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AN ANALYSIS OF THE REQUIREMENTS FOR, AND THE BENEFITS AND COSTS OF THE NATIONAL MICROWAVE LANDING SYSTEM (MLS)

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16. Abstract

This report consists of three volumes, i.e.: (1) An Executive Summary, (2) Volume I comprising the detailed study analysis, and (3) this Volume II which contains reprints of important studies supporting the analysis included in the report.

The analysis assesses the comparative desirability of implementing the MLS equipment option in place of the currently installed ILS as the long term National standard for precision guidance service. An evaluation period of 20 years, to the year 2000, was used for this assessment.

The study results show that implementation of MLS can provide sizeable benefits in excess of costs, in varying degrees, to the different aviation user groups (i.e., air carriers, commuter airlines, general aviation and the military).

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INTRODUCTION

This volume contains reprints of three reports that contributed in a significant way to the analysis included in this study report:

1. FAA Report No. ASP-75-1 develops the establishment criteria currently in use for installing the Instrument Landing System to Category I service levels.

2. Technical Report No. 7224 by the MITRE Corp. deals with the problems of future ATC systems with reduced spacing, attempting to cope with surveillance outages in the terminal area.

3. A report supplied by the Department of Defense on the benefits, quantified as cost savings, to the military services resulting from the implementation of the MLS. The report was prepared by Automation Industries Inc., Vitro Laboratories Division.

REPORT NO. ASP-75-1

ESTABLISHMENT CRITERIA FOR CATEGORY I INSTRUMENT LANDING SYSTEM (ILS)

DECEMBER 1975

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
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16. Abstract

This report develops revised establishment criteria for the Instrument Landing System (ILS) with approach lights based on benefit/cost analysis, as follows:

1. Air carrier airports with sustained turbojet operations are eligible for an initial ILS (same as previous criteria).
2. At other than jet-use carrier airports and for multiple ILS installations, criteria are expressed as a function of (a) annual instrument approaches by user category, and (b) nonprecision approach minimums on the candidate ILS runway. For example, a runway at a nonhub air carrier airport without turbojet service that has nonprecision approach minimums of 500-1 is an ILS candidate with any combination of 350 air carrier, 375 air taxi, or 1,500 general aviation annual instrument approaches.

The primary impacts of the revised criteria are to lower ILS establishment levels at air carrier airports and to raise them at general aviation airports. It is estimated that in the short term 81 additional air carrier runways and one addition general aviation runway would meet the revised numeric (but not necessarily other) criteria. Over the next 10 years, potential candidates under the revised criteria are about 95 percent of those under the previous criteria.

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EXECUTIVE SUMMARY

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3. Criteria for installing ILS at remote locations, for training, and for noise abatement have been retained.

The primary impacts of the revised criteria are to lower ILS establishment levels at air carrier airports and to raise them at general aviation airports. It is estimated that in the short term 81 additional air carrier runways and 1 additional general aviation runway would meet the revised numeric (but not necessarily other) criteria. Over the next 10 years, potential candidates under the revised criteria are about 95 percent of those under the previous criteria.

Benefits of an ILS vary widely, depending on the proportionate use of the ILS runway, the distribution of instrument weather at the airport, aircraft operating costs and average number of passengers, and other factors. Therefore, ILS candidates identified by means of establishment criteria will be screened in FAA Headquarters, using supporting data furnished by the regions with their responses to the annual Call for Estimates.

SECTION I - INTRODUCTION AND PURPOSE

Criteria for the establishment of terminal air navigation facilities and air traffic control services provided by the FAA are published in Airway Planning Standard Number One (APS-1) (Reference 1). These criteria are published to foster the planned development of a safe and efficient National Airspace System while at the same time guiding the allocation of resources for facilities and services.

The purpose of this report is to develop revised establishment criteria for the Category I Instrument Landing System (ILS). The new criteria are based on an analysis of the costs and benefits of ILS's and expressed in terms of annual instrument approaches (AIA) on the candidate runway.

According to APS-1, an airport is a candidate for the establishment of a facility or service when it meets the specified criteria and it is economically justified by a benefit/cost analysis. Recognizing the burden that would be placed on field facilities by requiring detailed benefit/cost analyses of potential candidates and their objections to such a procedure, ILS establishment criteria based on typical or normalized costs will be used by regional personnel to identify potential ILS candidates during preliminary budget formulation. Candidates thus identified will be screened and ranked by benefit/cost analysis in FAA Headquarters, using supporting data furnished by the regions with their responses to the annual Call for Estimates. Regional offices will have the option of using benefit/cost analysis to identify potential ILS candidates.

SECTION II - PREVIOUS ILS ESTABLISHMENT CRITERIA

Previous criteria for Category I ILS/MALSR, as published in APS-1, were:

1. Initial ILS

   a. Scheduled air carrier turbojet operations or

   b. 700 or more annual instrument approaches

2. Multiple ILS - airport total of 3,000 or more annual instrument approaches and 700 or more annual instrument approaches to each candidate ILS runway.

Provision also is made for installing ILS at remote locations, for training, and for noise abatement. A number of other requirements such as adequate runway length and runway edge lighting must be met to qualify for an ILS, but these are not pertinent here.

SECTION III - REVISED ESTABLISHMENT CRITERIA FOR CATEGORY I ILS

The benefits provided by a Category I ILS depend on a number of factors--the reduction in minimums the ILS gives, the relative amount of Category I weather at the airport, IFR flight activity at the airport and on the ILS runway, types of aircraft and numbers of passengers using the airport, and other factors. Two of the most important of these are the prospective users of the ILS and the reduction in minimums that the ILS will give. User category is important because ILS benefits are proportional to aircraft operating costs and numbers of enplaned passengers. The reduction in minimums determines the increase in runway utilization during instrument weather conditions with the ILS. For these reasons, user category and existing nonprecision approach minimums of the candidate ILS runway are included explicitly as variables in the "activity" establishment criteria. Revised establishment and discontinuance criteria for Category I ILS are:

1. Establishment

   An airport where scheduled air carrier turbojet operations are conducted on a sustained basis, or any other airport which meets the annual instrument approach criteria in paragraph 2, is a candidate for Category I ILS with an approach light system. (Provisions that are not relevant to this discussion have been omitted, e.g., the operation must be safe, runway lights are required, etc.)

2. Annual Instrument Approach Criteria

   An airport is a candidate for an initial or a multiple ILS with approach lights when the annual instrument approaches recorded for the runway on which the ILS is to be installed meet or exceed any combination of the conditions shown in Table 1.

3. Benefit/Cost Screening

   ILS candidates identified by the procedures in Table 1 will be screened in FAA Headquarters using the benefit/cost technique described in this report. FAA regional offices shall submit data required for screening purposes with their responses to the annual Call for Estimates. This provision does not apply to airports that qualify for an initial ILS under the air carrier turbojet service criterion.

TABLE 1

Annual Instrument Approach Criteria

User Category	Nonprecision Approach Minimums on the Candidate ILS Runway					
	300-3/4	400-3/4	400-1	500-1	600-1	700-1
Air Carrier						
Large Hub	300	200	150	100	75	50
Medium Hub	400	250	200	150	100	75
Small Hub	500	300	250	175	125	100
Nonhub	1,000	600	500	350	250	200
Air Taxi	750	550	475	375	300	225
General Aviation	2,500	2,000	1.800	1,500	1,200	900

NOTE: These AIA levels apply only when the ILS will give minimums of 200-½ or the equivalent; if lesser minimums are achievable, consult with the Office of Aviation System Plans to determine procedures (criteria) that are applicable.

To determine whether an airport meets Annual Instrument Approach (AIA) criteria:

- o Determine the least approach minimums currently authorized for the largest aircraft using the candidate runway, e.g., 500-1.
- o Reference the above table to select the qualifying numbers of AIA's on the candidate runway for each user category, e.g., small hub - 175, air taxi - 375, general aviation - 1500.*
- o Compute the number of recorded AIA's on the candidate runway for each user category as follows:
  1. Determine the AIA's by an on-site survey; or
  2. Calculate the AIA's by estimating the percentage of the total airport AIA's that used the candidate runway. Multiply this percentage by the total airport AIA's to determine the recorded AIA's.
- o Enter recorded and qualifying AIA's for the candidate runway as indicated below. The contribution of each category toward meeting the criteria is determined by summation. A runway with a total ratio of 1.0 or more meets the AIA criteria.

User Category		
Air Carrier:	Recorded AIA's / Qualifying AIA's =	x.xx
Air Taxi:	Recorded AIA's / Qualifying AIA's =	x.xx
General Aviation:	Recorded AIA's / Qualifying AIA's =	x.xx
Total Ratio		x.xx

*Hub designation is determined by enplanements at candidate airports.

4. Discontinuance

a. At an airport where scheduled air carrier turbojets operate the ILS shall not be decommissioned. At an airport where air carrier turbojet operations are discontinued and are not forecast to be resumed, the discontinuance criteria in 4(b) shall apply.

b. Airports having no scheduled air carrier turbojet operations are candidates for decommissioning of an ILS when the instrument approach activity falls to two-thirds* of the qualifying level. The decommissioning of an ILS shall be justified by a benefit/cost study.

Provisions for installing ILS at remote locations, for training, and for noise abatement have been retained.

*Annual O&M costs are about two-thirds of prorated investment costs.

SECTION IV - TYPICAL CATEGORY I ILS COSTS

A standard Category I ILS consists of a localizer and a glide slope, outer and middle marker beacons, and a 2,400-foot MALSR (Medium Intensity Approach Light System with Runway Alignment Indicator Lights). Distance measuring equipment (DME) may be used instead of marker beacons if the approach is over water or for some other reason the siting of the markers is impractical. A compass locator often is situated at the outer marker site, but it is not part of the ILS. A Category I ILS usually will give landing minimums of 200-foot decision height and one-half mile visibility (or Runway Visual Range 2400). Runway Visual Range (RVR) 1800 can be achieved with operative touchdown zone and runway centerline lights.

ILS/MALSR costs include the costs of the equipment and its installation, annual operation and maintenance, and flight inspection. ILS's also may require considerable grading to prepare the site and the removal of obstructions. Although these items are paid for by the airport sponsor, in most cases with ADAP assistance, they are required and have been included in the cost package. U. S. aircraft generally are well equipped to use the ILS so avionics costs have been disregarded in this report. Typical FY 1975 costs of major ground system components are summarized below:

Cost Item	ILS	MALSR	Total
Investment (000)			
Establishment	$219	$80	$299
Site Preparation	100	--	100
Total	$319	$80	$399
Annual O&M (000)			
Maintenance	$ 23	$ 7	$ 30
Stocks and Stores	9	1	10
Flight Inspection	9	--	9
Total	$ 41	$ 8	$ 49

The $219,000 ILS establishment cost is for a turnkey installation and may exclude some power line, monitor line, and related costs. ILS site preparation costs vary widely, from a few thousand dollars to more than a million dollars for unusually difficult sites. The "typical" site preparation cost shown on the preceding page was developed by Crosswell (Reference 2). Some items required for instrument approach capability have been omitted from the tabulation because the airport sponsor ordinarily would provide them in any case, e.g., adequate runway length, runway edge lighting, and rotating beam ceilometer.

SECTION V - ECONOMIC BENEFITS OF ILS

The primary quantifiable benefits of ILS are safety and efficiency. The precise lateral and vertical guidance an ILS gives reduces risk during approach and landing, particularly during instrument weather conditions. The decrease in flight disruptions (delays, diversions, and cancellations) associated with reduced landing minimums leads to a more efficient operation. Installation of an ILS also is believed to stimulate the demand for air transportation through greater reliability of service, contribute to the economic development of the community, and provide other but difficult-to-measure benefits; however, these latter benefits are not discussed in this report.

Costs of Flight Disruptions

Weather-caused flight disruptions--delays, diversions, and cancellations--impose economic penalties on both aircraft operators and passengers. Delays and diversions increase aircraft operating costs. Cancellations result in loss of revenue. All three types of disruptions create extra passenger handling expense (reticketing, meals, and overnight accommodations in some cases or providing alternate means of transportation.

Weather conditions of the kind that prevail when an airport is closed often persist for several hours, so that when delays are encountered they tend to be rather lengthy. Furthermore, delays beget delays. Temporarily closing one airport often leads to delays at subsequent stops along a route. The diversion of an aircraft from its intended destination may cause the cancellation of the following flight.

Most of the costs of flight disruptions are borne by the passengers, who suffer both delay and inconvenience. Since airports vary widely with respect to the numbers of passengers they handle, average number of enplaned passengers is a variable in the flight disruption cost estimating equations that have been developed.

Average flight disruption costs are developed in Appendix A and summarized on page 10 (A schematic illustration of the determination and application of these costs is shown in Figure 1).

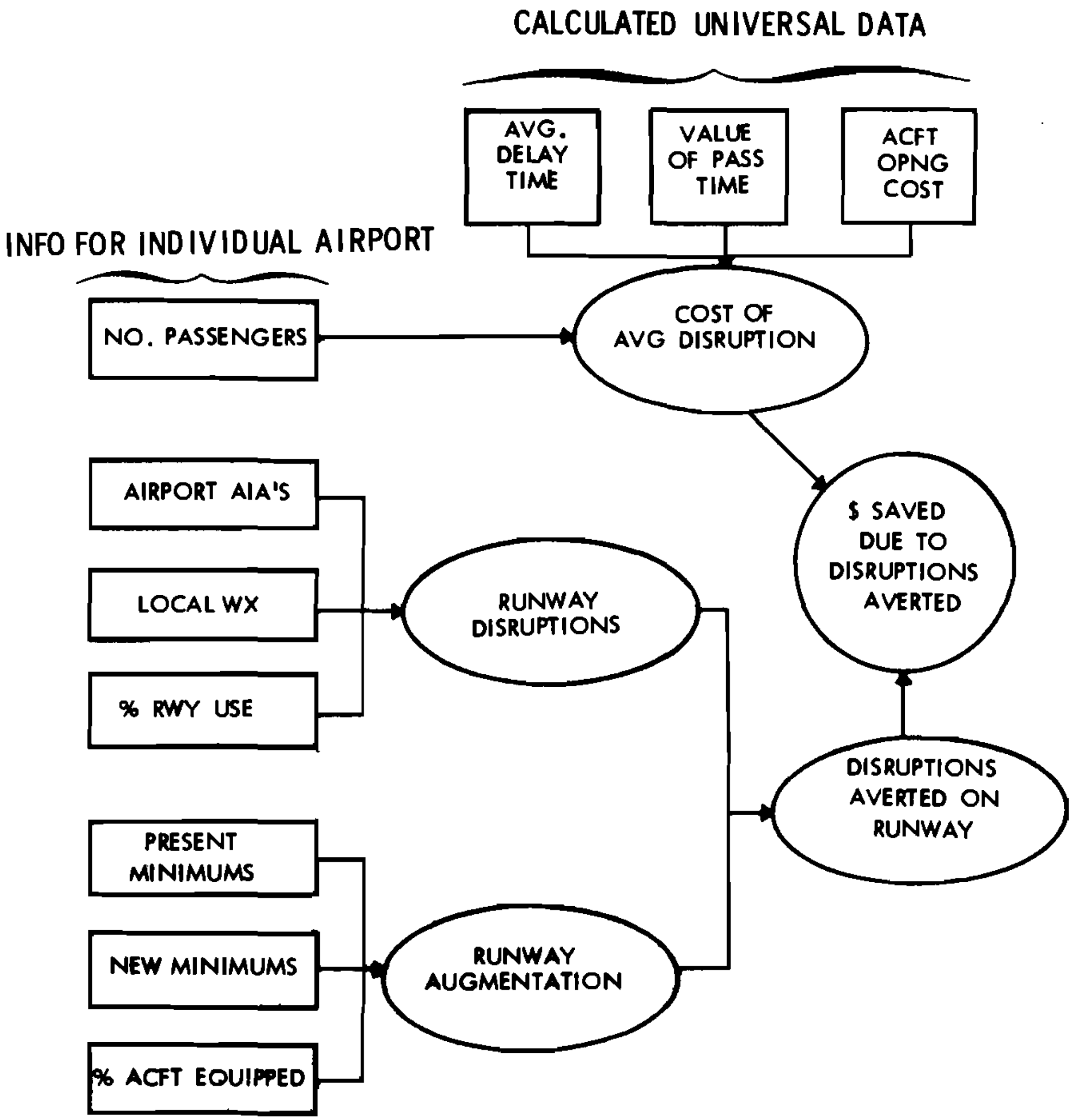

FIGURE 1. -- SCHEMATIC DETERMINATION OF COSTS OF FLIGHT DISRUPTIONS

Air Carrier		
Hub Airport	$48n +	$293
Nonhub Airport	97n +	60
Air Taxi	50n +	9
General Aviation	15n +	12

where n is the number of deplaning passengers

These equations were developed by estimating aircraft and passenger delay times associated with various types of flight disruptions and assigning costs to these delays. Average flight disruption costs were obtained by weighting each kind of disruption--delay, diversion, and cancellation--by its relative frequency of occurrence.

Passenger time lost, including primary plus secondary effects, was estimated to vary from 3/4 hour for a delayed general aviation aircraft to 7 1/2 hours for the diversion of an air carrier aircraft to an alternate airport and cancellation of the next flight. A value of $12.50 an hour was estimated for passenger time lost. Other costs entering into the equations (aircraft operating costs, extra passenger handling expenses, and revenue losses from flight cancellations) are detailed in Appendix A.

Numbers of passengers is a variable in each of the flight disruption cost estimating equations given above. For broad planning purposes, we can estimate the average number of passengers deplaning each type of flight and convert the cost equations above to average dollar values, as follows:

Type of Flight	Average Number of Deplaning Passengers*	Average Cost per Flight Disruption
Air Carrier		
Large Hub	54.0	$2,885
Medium Hub	38.1	2,120
Small Hub	29.7	1,720
Nonhub	8.1	845
Air Taxi	6.3	325
General Aviation	5.0	90

*Average number of deplaning air carrier passengers derived from CAB/FAA Airport Activity Statistics (Reference 3); air taxi passengers from CAB Commuter Air Carrier Traffic Statistics (Reference 4); passengers, including crew, aboard general aviation IFR flights estimated from itinerant flight survey data.

Safety Benefits

Benefits of risk reduction include the prevention of two kinds of accidents--nonprecision approach accidents during IFR conditions and VFR landing and runway accidents. Of these, the IFR approach accidents are by far the most costly, especially in numbers of aviation fatalities.

ILS safety benefits are derived in Appendix B. These benefits are based on a recently completed MITRE report (Reference 12) which identified approach and landing accidents that might have been avoided if precision approach facilities had been available and used. During the 9-year period 1964 through 1972, there were 81 possibly avoidable nonprecision approach accidents in this country which resulted in 170 fatalities:

User Category	Accidents	Fatalities
Air Carrier	6	48
Air Taxi	20	43
General Aviation	55	79
Total	81	170

Estimates of the safety benefits provided by an ILS through the prevention of nonprecision approach accidents were developed by converting numbers of accidents into accident rates and then dividing accident costs by the average number of approaches between accidents. This procedure gives a measure of the safety benefit per IFR approach provided by a precision approach aid.

Accident costs include loss or damage to property and loss or injury to human life. Aircraft replacement costs average about $6,000,000 for air carrier aircraft, $200,000 for air taxi aircraft, and $50,000 for general aviation aircraft. As nonprecision approach accidents often result in total destruction of the aircraft, it was estimated that loss or damage to aircraft averages 90 percent of replacement cost in these instances. Aircraft accident fatalities were costed at $300,000 each, a value based on non-Warsaw payment data furnished by the Civil Aeronautics Board.

During the same period, 1964-1972, small general aviation aircraft had 1,987 VFR approach accidents, with 191 fatalities, that might have been prevented with some sort of vertical guidance (ILS or VASI) and 6,684 runway accidents. The "risk cost" of these accidents was estimated to be about $0.50 per landing. About one-fourth of the general aviation fleet is equipped with glide slope. If pilots of these aircraft use the glide slope while making VFR approaches, the average benefit of an ILS for the prevention of VFR landing accidents is about 12 cents per itinerant landing. After making this adjustment and proportioning itinerant landings to instrument approaches, general aviation safety benefits were combined to represent the safety benefits per instrument approach.

Total safety benefits per instrument approach are tabulated below by user category and type of landing:

User Category	Benefit per IFR Approach of Preventable IFR Approach Accidents	Benefit per IFR Approach of Preventable VFR Landing Accidents	Total Safety Benefits per IFR Approach
Air Carrier			
Large Hub	$33	$*	$33
Medium Hub	25	*	25
Small Hub	20	*	20
Nonhub	10	*	10
Air Taxi	49	*	49
General Aviation	17	3	20

*Estimated to amount to one percent or less of the benefits of preventable IFR approach accidents.

Full benefit credit has been given for potentially preventable accidents despite the fact that some of these accidents might have occurred even if better guidance information had been available (precision approach accidents are less frequent and less serious, on the average, than nonprecision approach accidents, but they occur). This was done for two reasons. First, the benefit analysis has been limited to those accidents that have been judged as being possibly avoidable had better approach and landing aids been available.

The second and perhaps more important reason is a risk avoidance argument. There is evidence that Congress and the public are risk avoiders with respect to aviation safety, that in their eyes safety benefits weigh more heavily than economic benefits. Investments in landing aids are a form of insurance against potentially disastrous accidents and, as such, conform both to public sentiment and to FAA policy, which places safety above all other considerations.

This reasoning also pertains to the present Airway Planning Standard criterion which states that "An airport where scheduled air carrier turbojet operations are conducted on a sustained basis...is a candidate for a Category I ILS with an approach light system..." Proper alignment on approach is especially critical with large turbojet aircraft because of their size, speed, and relatively slow response times. The National Transportation Safety Board has recommended that vertical guidance be provided on all runways serving air carrier jet aircraft. For these reasons, and because of the high costs of air carrier accidents, the air carrier jet-use criterion for ILS has been retained.

SECTION VI - DERIVATION OF ILS ESTABLISHMENT CRITERIA

Safety and efficiency benefits have been combined and related to the benefits associated with an averted flight disruption for use in developing the numeric ILS criteria. Safety benefits apply to all instrument approaches, not only the additional approaches that the ILS permits. They vary, therefore, with the reduction in minimums that an ILS will give. Take, for example, a runway at which 100 nonprecision approaches were recorded last year. If the installation of an ILS will permit an additional 10 AIA's, efficiency benefits will accrue to the 10 additional flight completions but safety benefits will be realized by all 110 IFR approaches; the ratio of flights receiving safety vs. efficiency benefits thus is 11-to-1. If, on the other hand, the ILS permits an additional 50 AIA's, the ratio of flights receiving safety vs. efficiency benefits is 150-to-50, or 3-to-1.

Average increases in runway utilization during instrument approach weather conditions associated with reductions from nonprecision approach minimums to ILS minimums (200-½) are developed in Appendix C* and tabulated below:

Nonprecision Approach Minimums	Average Increase in Airport Utilization with ILS Minimums of 200-1/2
300-3/4	5.7%
400-3/4	11.3%
400-1	15.0%
500-1	22.4%
600-1	31.7%
700-1	44.9%

To compute the safety benefits associated with an averted flight disruption, multiply the benefit per IFR approach by a safety improvement factor which is the reciprocal of the reduction in minimums plus one. For example, a reduction in

*The more detailed data in Appendix C can be used to develop criteria for most combinations of nonprecision and precision approach minimums.

minimums of from 400-1 to 200-½ will give an average increase of 15 percent in runway utilization. The safety improvement factor (F) in this case is:

$$F = 1/0.15 + 1$$

$$= 1.15/0.15$$

$$= 7.7$$

These computations have been carried out for a range of nonprecision approach minimums and are shown by user category in Table 2. The efficiency benefit attributed to an averted flight disruption is constant, of course, regardless of the improvement in minimums the ILS gives. Safety benefits associated with an averted flight disruption are inversely proportional to the reduction in minimums--the smaller the reduction the greater the number of instrument approaches that will benefit per averted flight disruption from the safety provided by the ILS.

The computations in Table 2 assume that an ILS will give minimums of 200-½, regardless of the current nonprecision minimums up to a maximum of 700-1. This is not always the case, of course, although in many circumstances it will be. An airport with circling minimums off a VORTAC located 20 miles away usually will have nonapproach minimums approximating 700-1; unless there are obstructions near the airport, there is no obvious reason why the ILS shouldn't give minimums of 200-½ in this typical case. To cite another example, the VOR minimums for John F. Kennedy International Airport's Category II runway are 600-1 for Categories A and B (small) aircraft, 600-1½ for Category C aircraft, and 600-2 for Category D (large jet) aircraft; La Guardia Airport's Category II runway has even more restrictive VOR minimums. Charlottesville-Albemarle Airport's Runway 3 has ILS minimums of 200-½ and NDB minimums of 800-1 for Category C aircraft. The "200-½" assumption underlying Table 2, in other words, does not seem unreasonable.

On the other hand, there are many runways where minimums of 200-½ cannot be achieved with an ILS; in these instances the numeric criteria developed from Table 2 would not apply. Alternate criteria can be developed for these special cases and, of course, the impact of the less-than-optimum minimum reductions would show up during the benefit/cost screening.

TABLE 2

ILS Safety and Efficiency Benefits Combined and Related to the Benefits of an Averted Flight Disruption

User Group and Benefit Category	Current Nonprecision Approach Minimums					
	300-3/4	400-3/4	400-1	500-1	600-1	700-1
Air Carrier						
Large Hub						
Safety Benefits	$ 610	$ 325	$ 255	$ 180	$ 135	$ 105
Efficiency Benefits	2,885	2,885	2,885	2,885	2,885	2,885
Total	$3,495	$3,210	$3,140	$3,065	$3,020	$2,990
Medium Hub						
Safety Benefits	$ 465	$ 245	$ 190	$ 135	$ 105	$ 80
Efficiency Benefits	2,120	2,120	2,120	2,120	2,120	2,120
Total	$2,585	$2,361	$2,310	$2,255	$2,225	$2,200
Small Hub						
Safety Benefits	$ 370	$ 195	$ 155	$ 110	$ 85	$ 65
Efficiency Benefits	1,720	1,720	1,720	1,720	1,720	1,720
Total	$2,090	$1,915	$1,875	$1,830	$1,805	$1,785
Nonhub						
Safety Benefits	$ 185	$ 100	$ 75	$ 55	$ 40	$ 30
Efficiency Benefits	845	845	845	845	845	845
Total	$1,030	$ 945	$ 920	$ 900	$ 885	$ 875
Air Taxi						
Safety Benefits	$ 900	$ 475	$ 375	$ 275	$ 200	$ 150
Efficiency Benefits	325	325	325	325	325	325
Total	$1,225	$ 845	$ 700	$ 600	$ 525	$ 475
General Aviation						
Safety Benefits	$ 370	$ 200	$ 150	$ 110	$ 85	$ 65
Efficiency Benefits	90	90	90	90	90	90
Total	$ 460	$ 290	$ 240	$ 200	$ 175	$ 155

Discounted Costs and Benefits

The Office of Management and Budget has prescribed a standard 10 percent discount rate to be used in evaluating the measurable costs and/or benefits of programs or projects when they are distributed over time (Circular No. A-94, Revised). Over 15 years, the discount factor is 7.605. This factor was used to discount ILS operations and maintenance (O&M) costs.

ILS benefits are a function of traffic activity. Since air traffic is expected to increase throughout the next 15 years, net discount factors have been developed in Table 3 by multiplying OMB's discount factors by FAA's median forecast factors for 1975-1986 (Reference 9, extrapolated to 1990). These net discount factors, summed over the next 15 years, are: air carrier - 9.141; air taxi - 15.346; general aviation - 12.123.

Discounted lifetime ILS costs thus become:

Cost Item	Cost (000)	Discount Factor	Discounted 15-Year Costs (000)
Investment	$399	1.000	$399
Annual O&M	49	7.605	373
Total			$772

The 15-year streams of discounted benefits per averted flight disruption, by user group, were obtained by multiplying the values of Table 2 by the appropriate net discount factors. The results of these computations are given in Table 4.

TABLE 3

Discount Factors

Year After Funding	10% Discount Factor	IFR Growth Factors 1975-1990			Net Discount Factors for Benefits*		
		AC	AT	GA	AC	AT	GA
1	.909	1.035	1.120	1.067	0.941	1.018	0.970
2	.826	1.071	1.254	1.140	.885	1.036	.942
3	.751	1.109	1.404	1.216	.833	1.054	.913
4	.683	1.148	1.574	1.299	.784	1.075	.887
5	.621	1.188	1.762	1.386	.738	1.094	.861
6	.564	1.229	1.974	1.480	.693	1.113	.835
7	.513	1.247	2.122	1.591	.640	1.089	.816
8	.467	1.266	2.281	1.710	.591	1.065	.799
9	.424	1.285	2.452	1.839	.545	1.040	.780
10	.386	1.304	2.636	1.976	.503	1.017	.763
11	.350	1.324	2.834	2.125	.463	.992	.744
12	.319	1.344	3.046	2.284	.429	.972	.729
13	.290	1.364	3.275	2.455	.396	.950	.712
14	.263	1.384	3.521	2.640	.364	.926	.694
15	.239	1.405	3.785	2.838	.336	.905	.678
	7.605				9.141	15.346	12.123

*10% discount factor multiplied by IFR growth factor.

TABLE 4

Discounted 15-Year Benefits Associated
with an Averted Flight Disruption
(in thousands of dollars)

User Category	Current Nonprecision Approach Minimums					
	300-3/4	400-3/4	400-1	500-1	600-1	700-1
Air Carrier						
Large Hub	$31.2	$29.3	$28.7	$28.0	$27.6	$27.3
Medium Hub	23.6	21.6	21.1	20.6	20.3	20.1
Small Hub	19.1	17.5	17.1	16.7	16.5	16.3
Nonhub	9.4	8.6	8.4	8.2	8.1	8.0
Air Taxi	18.8	12.3	10.7	9.2	8.1	7.3
General Aviation	5.6	3.5	2.9	2.4	2.1	1.9

SECTION VII - APPLICATION OF ILS AND BENEFIT/COST CRITERIA

This section illustrates by means of worksheets the application of the ILS criteria and of the benefit/cost criteria. The two applications are similar except that the benefit/cost criteria are more detailed.

The worksheet on the next page shows how a regional office might determine whether a runway was a candidate for an ILS. It also lists the information to be supplied for each ILS candidate submitted in response to the annual Call for Estimates. All of the required data should be readily available from or easily estimated by the airport operator or the local tower chief. Filling out the form takes only a few minutes.

The second worksheet illustrates the application of the benefit/cost procedure. Airports differ with respect to the average numbers of passengers per flight, and local weather patterns are quite variable. To take account of these differences, candidate ILS locations identified by means of the establishment criteria will be screened in FAA Headquarters by benefit/cost analysis.

In the example shown in the worksheets, Runway 21 at Joe Foss Field in Sioux Falls, North Dakota, the establishment criteria gave a ratio of recorded-to-qualifying AIA's of 2.2. The benefit/cost ratio was somewhat lower, 1.7. This happened because the number of enplaning air carrier passengers at Joe Foss Field is less, on the average, than that at most small hub airports. (It often happens that arriving flights carry through passengers, in which case the number of persons aboard aircraft and benefiting from the ILS will, on the average, exceed the average number of enplaning passengers. In these cases, the regions should estimate the actual number of passengers on board for use in the benefit/cost analysis.)

The benefit/cost worksheet will not be used in actual practice; the procedure has been computerized. However, it does show the steps in the procedure, which may be of interest to some readers. These are:

1. Determine the old and new approach minimums. An ILS, for example, might lower minimums for a runway from 400-1 to 200-½. Requires regional input.

2. From weather records, determine the percentage increase in runway utilization during IFR weather conditions that

WORKSHEET FOR APPLICATION OF ILS CRITERIA

Location: *Sioux Falls, S. D.* Runway *21*

Airport: *Joe Foss Field* Hub Type *Small*

IFR Minimums: Nonprecision *400-3/4* ILS *200-1/2*

Estimated IFR Use of Candidate Runway *30%*

AIA's on Candidate ILS Runway (FY-1974):

	1974 AIA's	Runway Use Factor	AIA's on Candidate Rwy
Air Carrier	2,032	.30	610
Air Taxi	89	.30	27
General Aviation/Military	1,089	.30	327

Proportion of Criteria Satisfied:

	Recorded AIA's	Qualifying AIA's	Ratio
Air Carrier	610	300	2.03
Air Taxi	27	550	.05
General Aviation/Military	327	2,000	.16
Total			2.24

Data to be Furnished by Region:

Estimated ILS Minimums *200-1/2*

Estimated IFR Use of Candidate Runway *30%*

Average Number of Passengers

Air Carrier *18.3*

Air Taxi *6.3*

General Aviation *5.0*

WORKSHEET FOR APPLICATION OF BENEFIT/COST ANALYSIS

Location *Sioux Falls, S. D.* Runway *21*

Airport *Joe Foss Field* Hub Type *Small*

IFR Minimums: Nonprecision *400-3/4* ILS *200-1/2*

Increase in Candidate Runway Use with ILS *11.3%*

Estimated IFR Use of Candidate Runway *30%*

ILS-equipped IFR Aircraft: Air Carrier *100%*

Air Taxi *100%* General Aviation *90%*

IFR Augmentation Factors:

Air Carrier *11.3% x 30% x 100% = 0.0339*

Air Taxi *11.3% x 30% x 100% = 0.0339*

General Aviation *11.3% x 30% x 90% = 0.0305*

Avertable Flight Disruptions:	FY-1974 AIA's	IFR Aug. Factor	Avertable Flt. Disruptions
Air Carrier	2,023	.0339	69
Air Taxi	89	.0339	3
General Aviation/Military	1,089	.0305	33

Cost per Flight Disruption:	Cost Formula	Av. No. of Pass.	Cost per Disruption
Air Carrier	$48n + $293	18.1	$1,711
Air Taxi	50n + 9	6.3	324
General Aviation	15n + 12	5.0	87

Safety Benefit per Flt. Disr.:	Benefit per IFR Approach	Safety Improvement Factor	Benefit per Disruption
Air Carrier	$20	9.8	$196
Air Taxi	49	9.8	480
General Aviation	20	9.8	196

Total Benefits FY-1974:	Total Benefit per Flight Disruption	Avertable Flight Disruptions	Total FY-1974 Benefits
Air Carrier	$1,367	69	$94,323
Air Taxi	804	3	2,412
General Aviation	283	33	9,339

Discounted 15-Year Benefits:	Total FY-1975 Benefits	Net Discount Factor	Discounted 15-Year Benefits
Air Carrier	$94,323	9.141	$862,207
Air Taxi	2,412	15.346	37,015
General Aviation	9,339	12.123	113,217
Total			$1,012,439

Benefit/Cost Ratio: 15-year discounted benefits: *$1,012,439*
15-year discounted costs: *$ 772,000*
Ratio: *1.3*

the new minimums will permit. Sources of weather data are discussed in Appendix C.

3. Estimate the proportionate use of the candidate runway for instrument approaches, e.g., the runway on which the first ILS at an airport is installed may handle 60 percent of the instrument approaches at the airport, the second ILS 30 percent, the third ILS 15 percent (since there probably would be some realignment of runway use with the additional ILS), etc. Requires regional input.

4. Estimate the proportion of instrument approaches that will be by aircraft equipped to use the new ILS. (For systems for which few aircraft are equipped such as the Category IIIA ILS, the ISMLS, and the MLS, this will be an important factor.)

5. Multiply 2. through 4. above, which gives an "IFR augmentation factor," a measure of the proportion of flight disruptions that will be averted by means of the new facility.

6. List instrument approaches recorded at the airport, by user category, during the most recent year and multiply by the IFR augmentation factor. This gives the number of averted flight disruptions.

7. Compute the cost per flight disruption by inserting the average number of deplaning passengers (or passengers on board) into the cost estimating equations developed in Appendix A. May require regional input.

8. Compute the safety benefit per flight disruption by multiplying the benefit per IFR approach (Appendix B) by the safety improvement factor associated with the increase in runway utilization.

9. Sum the flight disruption and safety benefits and multiply by the number of avertable flight disruptions. This gives total benefits for the current year, by user category.

10. Multiply current year benefits by the net 15-year discount factors, by user group, which gives lifetime benefits.

11. Divide discounted 15-year benefits by costs to get the benefit/cost ratio for the runway.

SECTION VIII - IMPACT ASSESSMENT

The revised criteria lower ILS establishment levels at air carrier airports and raise them at general aviation airports. The new criteria also explicitly recognize and give credit for operations by air taxi aircraft.

One way to assess the impact of the revised criteria would be to ask FAA's regional offices to identify, runway-by-runway, those locations meeting the previous and revised ILS (or MLS) criteria over the next 10 years. This procedure would eliminate locations where an ILS is not feasible for one reason or another; however, it is not practical at this time. Alternatively, one can apply the two sets of criteria to current and forecast instrument approach activity, as has been done below. Revised ILS criteria associated with reductions in minimums of from 500-1 and 400-1 to 200-½ were selected as being representative of the average situation.

Locations meeting numeric criteria were identified by applying the previous and revised criteria to AIA's listed in FAA's FY-1974 Air Traffic Activity report. Estimates of additional qualifiers through FY-1986 were obtained by deflating establishment levels under the two sets of criteria by IFR activity growth factors shown in official FAA forecasts (air carrier - 1.3, air taxi - 2.6, general aviation - 2.0).

In applying the criteria, it was estimated that the first ILS at an airport will handle 60 percent of the instrument approaches; the second ILS 30 percent; and the third ILS 15 percent, since there probably would be some realignment of runway use with the additional facilities. (It has been argued that multiple ILS installations should be based on the marginal improvement the ILS gives, i.e., if one ILS handles 60 percent of the AIA's and two ILS's 80 percent, the second ILS gives a 20 percent improvement; if three ILS's handle 90 percent of the instrument approaches, the third gives a 10 percent improvement, etc. However, this reasoning is not applicable here because the benefits given by an ILS are proportional to the actual numbers of instrument approaches served.)

By means of this procedure, locations meeting numeric criteria have been identified. It should be noted that locations meeting numeric criteria are not necessarily candidates for an ILS: The installation may not be technically feasible; obstacles around the airport may preclude a precision approach;

the airport sponsor may not be willing to prepare the site or provide the required runway length or lighting; or there may be community resistance to an ILS. The tabulation in Table 5, for example, lists 83 non-ILS runways that met the previous numeric criteria. In other words, identifying numeric qualifiers gives an estimate of the relative impact of the two sets of criteria but not of the absolute impact.

As background for an impact assessment, it may also be helpful to review the current ILS inventory, including systems budgeted for but not yet installed. All large- and medium-hub airports are well-equipped with ILS. Eighty-three of the 84 small-hub airports have ILS, and 32 have multiple systems. Of the nonhub air carrier airports, all but 4 recording 500 or more AIA's in FY-1974 have or are programmed for ILS. Finally, about 90 general aviation airports are equipped with ILS.

Large- and medium-hub airports were excluded from the impact assessment because these airports have enough instrument approach activity to justify ILS on practically every runway where it is needed. Airports qualifying for an initial ILS under the air carrier jet-use criterion were omitted because this criterion has not been changed. Previous and revised ILS criteria were applied to small-hub and nonhub air carrier airports and to general aviation/air taxi airports.

The results of this analysis are summarized in Table 5. In the short term, 81 additional air carrier runways and one additional general aviation runway meet the revised criteria. Over the next 10 years, potential candidates under the revised criteria are about 95 percent of those under the previous criteria. The reason for this is that although air carrier runway establishment levels have been relaxed, the number of potential air carrier candidates is limited.

TABLE 5

Numbers of Runways Meeting the Previous and Revised ILS Establishment Criteria for Specified Airport Types FY-1976 and FY-1986

Type Airport, Year, and ILS	Estimated Number of Runways Meeting Numeric Criteria		
	Previous Criteria (P)	Revised Criteria (R)	R-P
Air Carrier Airports			
Medium and Small Hub			
FY-1976			
Second ILS	14	46	+32
Third ILS	15	48	+33
Add'l thru FY-1986			
Second ILS	12	8	- 4
Third ILS	13	12	- 1
Total	54	114	+60
Nonhub			
FY-1976			
First ILS	1	4	+ 3
Second ILS	5	18	+13
Add'l thru FY-1986			
First ILS	---	3	+ 3
Second ILS	8	5	- 3
Total	14	30	+16
General Aviation/Air Taxi Airports			
FY-1976			
First ILS	32	18	-14
Second ILS	16	31	+15
Add'l thru FY-1986			
First ILS	49	2	-47
Second ILS	43	4	-39
Total	140	55	-85
All Specified Airports			
FY-1976	83	165	+82
Add'l thru FY-1986	125	34	-91
Total	208	199	- 9

SECTION IX - SENSITIVITY ANALYSIS

Table 2 on page 16 gives some insight into the relative contributions of safety and efficiency benefits to the total. Efficiency benefits predominate for the air carriers. For general aviation and air taxi, safety benefits play a larger role.

Flight disruption benefits are principally dependent on four factors: (1) reduction in weather minimums, which determines the number of flight disruptions averted; (2) average number of deplaning passengers; (3) delay time caused by a disruption; and (4) the value of a passenger's time. The first two factors can be factually determined for any airport. For a sample of airports examined, these factors varied by as much as 10:1 and 7:1, respectively. They are the primary determinants of whether or not an ILS is justified. The third and fourth factors are based on our best estimates as outlined in Appendix A.

If the value of passenger time is halved (or the delay estimate halved, which has a similar impact), benefits are reduced from between 40 percent for large air carrier airports with 700-1 minimums on the candidate runway to 10 percent for general aviation runways with 300-3/4 minimums. This suggests that for air carrier airports the analysis is highly sensitive to the value of passengers' time. In the long run this would follow, of course, but in the short term most air carrier candidates exceed the qualifying levels by comfortable margins to that the effect of such a change would be lessened. At general aviation airports, safety benefits comprise a greater percentage of total benefits so reducing the value of passengers' time would have a minor impact.

With respect to safety benefits, substantial credit was taken for nonprecision approach accidents deemed preventable with the installation of an ILS. During the 10-year period studied, numbers of nonprecision approach accidents exceeded precision approach accidents by about 50 percent, and the nonprecision accidents resulted in more than twice as many fatalities. Offsetting nonprecision by precision approach accident costs would reduce air carrier establishment levels by from 5 to 20 percent, reduce air taxi establishment levels by from 15 to 35 percent, and reduce general aviation establishment levels by from 20 to 40 percent.

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APPENDIX A

COSTS OF FLIGHT DISRUPTIONS

Effects of Weather-Caused Flight Disruptions*

1. Air Carrier

Weather-caused flight disruptions--delays, diversions, and cancellations--impose economic penalties on both aircraft operators and passengers. Delays and diversions increase aircraft operating costs. Cancellations result in loss of revenue. All three types of disruptions create extra passenger handling expense for the airlines. However, most of the costs of flight disruptions are borne by the passengers, who suffer inconvenience and delay. Since airports vary widely with respect to the numbers of passengers they handle, average number of enplaned passengers is a variable in the flight disruption cost estimating equations developed in this appendix.

In long-haul operations, airlines seldom cancel because the destination airport is forecast to be closed. If on arrival the destination airport is open or is forecast to open within an hour or so, the aircraft will proceed to its destination and either land or hold. Otherwise, it will divert to another airport.

Short- and medium-haul flights tend to take delays on the ground at the departure airport to save fuel and to ease congestion problems at the arrival airport. This saves equipment operating costs but not the cost of passenger delay time. If the below-minimum weather at the destination is forecast to persist, the flight may be cancelled. If the airport is an intermediate stop along a route, it may be overflown, creating a diversion for passengers intending to land and a cancellation for those expecting to board the aircraft.

Airport size and facilities also affect flight behavior. All large-, medium-, and small-hub** airports (except Palm Springs, California) have one or more ILS's. Airport

* The methodology used herein to estimate the costs of weather-caused flight disruptions is an adaptation of that developed by United Research Incorporated (References 5, 6)

** The air traffic hub structure as developed by FAA and used to measure the concentration of civil air traffic by communities.

closures will tend to be of shorter duration at these airports than at less well-equipped airports; and since large airports usually are served by larger aircraft, on the average, than small airports, costs of diversions and cancellations are relatively high. Consequently, flights into large airports are relatively more likely to be delayed, rather than diverted or cancelled, than flights into small airports. Because of these differences, separate flight disruption cost estimating equations have been developed for large airports (large, medium, and small hubs) and for small airports (nonhub).

Relative Frequency of Flight Disruptions. CAB statistics show that about 2.6 percent of air carrier departures scheduled at large-, medium-, and small-hub airports in CY-1973 were cancelled, while at nonhub airports the cancellation rate was 8.5 percent, or more than 3 times higher (Reference 3):

Hub Classification	Number of Hubs	CY-1973 Aircraft Departures Scheduled	Scheduled Completed* Number	Percent
Large	25	2,639,893	2,572,093	97.4
Medium	39	1,010,902	988,496	97.8
Small	84	675,043	651,772	96.6
Subtotal	148	4,325,838	4,212,361	97.4**
Nonhub	624	611,166	559,265	91.5
U. S. Total	772	4,937,004	4,771,626	96.7**

* Excludes extra sections of scheduled flights.

** Average percentage.

Fromm (Reference 6) determined several years ago that about two-thirds of air carrier cancellations, on an annual basis, were due to weather causes. He also found that air carrier diversions were about one-sixth as frequent as cancellations and that five-sixths of these diversions were caused by weather. These figures seem reasonable today and have been used here to estimate the proportions of cancellations and diversions at large-, medium-, and small-hub airports, as follows:

Weather-caused cancellations = 2.6% x 2/3

= 1.7% of all flights

Weather-caused diversions = 2.6% x 1/6 x 5/6

= 0.4% of all flights

Air Transport World magazine (Reference 7) has for a number of years published CAB data on the on-time arrival performance of the trunk air carriers. Averages for CY-1972 and CY-1973, weighted by numbers of scheduled departures per carrier, were as follows:

Performance Measure	Percentage CY-1972	Percentage CY-1973
On-time or within 15 minutes	74.1	70.1
Over 15 minutes late	24.2	27.7
Cancelled flights	1.7	2.2
Total, trunk air carriers	100.0	100.0

This data indicates that delays to trunk air carrier aircraft are 12 to 14 times more frequent than flight cancellations. No information is available about the breakdown of these delays by cause, i.e., below-minimum weather, mechanical problems, late equipment, airport congestion, etc. However, delay data submitted by 3 airlines to the FAA over a 6-year period, 1964-1969, indicated that about 25 percent of delayed arrivals were delayed because of weather; about 2 percent of departing aircraft were reported delayed because of weather (Reference 8). (Although only one-fourth of total delays were attributed to weather, data collected by the FAA through its NASCOM program shows that of delays to IFR aircraft of over 30 minutes, about 50 percent are due to weather causes.)

Recapitulating, we have for fairly busy air carrier airports:

Weather-caused Flight Disruptions	Large Air Carrier Airports Percent of All Flights	Large Air Carrier Airports Normalized Distribution
Delays*	6.5*	75
Diversions	.4	5
Cancellations	1.7	20
Total	8.6	100

*26% of flights delayed times 25% of delays due to weather equals 6.5% of all flights delayed because of weather and associated congestion.

Based on the percentage of air carrier cancellations at nonhub airports (8.5 percent), 5 or 6 percent of flights scheduled into these airports may overfly the stop. Assuming the same percentage distribution of delays, diversions, and cancellations as for larger airports, but adding 5 percent overflights, gives for nonhub airports:

Weather-caused Flight Disruptions	Nonhub Air Carrier Airports Percent of All Flights	Nonhub Air Carrier Airports Normalized Distribution
Delays	6.5	48
Diversions	.4	3
Cancellations	1.7	12
Overflights	5.0	37
Total	13.6	100

Aircraft Delays. An average delay of 45 minutes waiting for the weather to improve was applied to delayed aircraft. Weather conditions of the kind that prevail when an airport is closed (usually fog) often persist for several hours so that when delays are encountered, they tend to be rather lengthy. If the airport is forecast to be closed for several additional hours, flights may be cancelled or, if already airborne en route, diverted to an alternate airport.

After the weather improves (it usually remains low visibility IFR), the queue which has built up must be reduced, and subsequent flights must take their turn in line. The net effect at a busy airport could easily be to more than double the average waiting time. In slow hours, or at less busy airports, this effect would be much smaller. For this analysis the average delay time was estimated to be 45 minutes at nonhub airports and 75 minutes at hub airports (45 minutes waiting for the weather to improve plus 30 minutes wait in queue). It was also assumed that 50 percent of the aircraft delays will be taken on the ground.

Aircraft Diversions. Diverting an aircraft from, say, Kennedy International to Dulles International Airport is a costly procedure. Additional flying time may be incured in holding over the original destination airport, in flying to an alternate destination, and, possibly, in holding over the alternate. When the weather improves, the aircraft usually must be ferried to another airport before it can resume normal scheduled operations. It is estimated that diversions require one hour extra flying time, averaged for all diversions including those that are diverted prior to entering the terminal area of the destination airport but excluding overflights which merely proceed to the next destination. Repositioning aircraft requires an estimated one-half hour ferry flight. Total additional flight time per diversion thus is 1½ hours.

Airlines also incur passenger service expense as a result of flight diversions. Passengers must be transported from the alternate airport to their intended destination, either on a later flight or by surface transportation. In some instances, meals and overnight lodging are provided. Per-passenger costs to the airlines for these expenses are estimated to average $30, including $25 for the return trip to the original destination plus a prorated average of $5 per passenger for those who must be fed, housed, or otherwise accommodated.

Finally, it is necessary to consider the time lost by passengers. One hour is lost because of additional flying time. To this must be added the additional amount of time required for the passenger to reach his desired destination. If the return trip is by air, an extra hour or so of flight time is involved plus perhaps 3 hours waiting for the destination airport to open. If surface Transportation is used, a similar amount of time is likely to be required to arrange for the alternate transportation and for the actual travel time. Total time lost due to a flight diversion thus adds up to 5 hours per passenger.

Flight Cancellations. When a flight is cancelled, the airline must arrange reservations on a future flight, if the passenger still wants to go, and issue new tickets. Meals must be provided some passengers and, occasionally, overnight lodging. These extra handling expenses, averaged for all passengers whether continuing their trip at a later time or not, are estimated to approximate $2 per passenger.

As with diversions, aircraft sometimes must be repositioned after a flight is cancelled. An average of one-half hour extra flying time for ferrying aircraft is assumed, the same as for diverted aircraft, and it is estimated that one-third of cancelled aircraft must be repositioned. Averaged for all cancellations, this yields 10 minutes' extra flying time per cancellation (one-half hour applied to one-third of the cancellations).

Airlines also are subject to losses of passenger revenue because some passengers may shift to other means of transportation and others may cancel their trip. The decision to cancel or not is influenced by many factors, including the length of the trip involved, whether the cancelled flight is the outbound or the return trip, the expected duration of below-minimum weather, the availability of alternative means of transportation, the purpose of the journey, etc. Based on discussions with airline personnel, Fromm (Reference 6) developed estimates of the percent of booked passenger revenue retained by air carriers, as a function of length of passenger journey. Since those estimates were developed, aircraft speeds have increased and the overall reliability of air transportation has improved. Consequently, Fromm's estimates have been revised, as follows:

	Percent of Booked Passenger Revenue Retained by Air Carriers	
Length of Flight	Fromm's Estimate	Revised Estimate
0 - 499 miles	30%	60%
500 - 999 miles	55%	75%
1,000 miles or over	80%	90%

Applying the preceding cancellation revenue retention percentages to passenger mile data gives an average rate of revenue retention of about 80 percent. This percentage was applied to cancellations at all airports, large and small, as a departure from a small airport often is but the first leg of a longer trip. Domestic airline passenger trip lengths averaged about 700 miles in FY-1974 (Reference 9) (international trips seldom are cancelled). At 10 cents per passenger mile, revenue per trip thus averages $70. With a revenue retention rate of 80 percent, the revenue loss attributable to a cancellation averages about $14 per passenger.

Revenue losses when flights are cancelled are offset by savings in direct aircraft operating costs of the potential flight. The average duration of a trunk air carrier aircraft flight in FY-1974 was 1.25 hours; for local service carriers flight durations averaged 0.58 hours (References 3, 10).

Trunk airlines typically operate from hub airports, whereas local service airlines are more representative of the kinds of activities found at nonhub, air carrier airports. Average aircraft operating costs are applied to these typical flight durations in the development of flight disruption cost estimating equations.

As with other kinds of flight disruptions, passengers are subjected to delay and a loss of productive time when a flight is cancelled. If the cancelled flight is the return portion of a long trip, the passenger has little recourse but to wait until the airlines start flying again. If, on the other hand, he is given ample notice of the cancellation, cancels his trip, and is able to adjust his schedule accordingly, he may suffer no delay.

Airlines seldom cancel flights on account of weather unless the weather is very poor and is forecast to remain so for several hours. As the flight that is cancelled may have been scheduled to depart some time during this period, the delay waiting for the weather to improve may average 2 hours. After the weather improves, passengers continuing their trips by air must find another flight going their way and get reservations. This can easily add 3 hours' or more additional delay. Assuming a total delay of 5 hours, on the average, when flights are cancelled, and applying this delay to 80 percent of cancelled passengers who elect to continue their trips by air, gives an average of 4 hours' delay per cancelled passenger. These long delay times may seem excessive, but is should be noted that airlines ordinarily do not cancel flights unless the destination airport (or if the weather is bad enough, the departure airport) is forecast to be below minimums for a considerable period of time. If closures of shorter duration are forecast, they usually will delay on the ground at the departure airport.

Overflights. An overflight does not increase aircraft operating costs; in fact, when a stop is bypassed and the aircraft proceeds directly to its next destination, total flying time is reduced. These savings are offset in those instances when the pilot holds for a few minutes over his intended destination while he decides whether he should or should not attempt a landing.

An overflight results in a diversion for passengers intending to deplane and a cancellation for passengers intending to board the aircraft. The airlines incur extra passenger handling expenses when stops are overflown, just as they do with other diversions and cancellations; and passengers, whether enplaning or deplaning, experience delays. For these reasons, in this study an overflight has been equated to a diversion plus a cancellation and, except for increased aircraft operating costs, costed accordingly.

Secondary Effects of Delays. When an aircraft is delayed, say an hour, the flight on which the equipment next goes out (or the next leg of a continued flight) will also be delayed. Equipment turnaround time, however, normally includes slack time, say 15 minutes. By foregoing scheduled slack time at intermediate stops, delayed flights are able to make up some lost time during subsequent flights between city pairs. Nevertheless, passengers boarding later flights would still have waited for the delayed flight to arrive. Passengers waiting at airports on the next one or two legs of the delayed flight would experience practically as much delay as those on the preceding legs. If many intermediate stops are made, only enplaning passengers at later legs will experience minor delays.

The effect is essentially the same when an aircraft makes stops on a through flight. Stops are generally scheduled to take a minimum amount of time on the ground to minimize inconvenience to passengers aboard the aircraft. In such cases, very little can be saved at a stop, and passengers who board the aircraft when it stops have the delay inflicted on them.

There are, however, integrating factors which offset the cumulative effect of delays. For one thing, delays will sometimes occur in the evening when an aircraft is through flying for the day or has but one or two more trips to make. Perhaps more important than the foregoing, airlines do not generally schedule equipment for the tight turnarounds suggested above. Indeed, they often permit rather large gaps in equipment schedules during the day. This is presumably done because of the vagaries of consumer demand--for example, equipment is frequently scheduled for departure on the hour or half-hour. The price airlines pay to give such service is less-than-full equipment scheduling. Customer demand also leads airlines to allow equipment to sit on the ground for extended periods during the day and in the late evening. The very existence of air carrier morning and early evening traffic peaks attests to the fact that airlines behave in this manner.

Finally, at the largest airports, airlines can often use other equipment to back up a flight that is delayed. Such reshuffling of equipment is one of a dispatcher's key functions; he may dead-head equipment that is temporarily idle to close a gap on a delayed flight.

For all of the foregoing reasons, it is an exaggeration to say that a flight delay at the initial leg of the trip will result in cumulative delays to subsequent passengers. In this analysis, it was assumed that 45 minutes of weather-caused delay at hub airports gives rise to 2 hours' passenger delay--45 minutes of weather delay plus 30 minutes in queue plus 45 minutes' delay to subsequent flights. At nonhub airports queues are unlikely, so it was assumed that 45 minutes of flight delay would result in a total of 1½ hours of passenger delay.

Secondary Effects of Diversions and Cancellations. The diversion of an aircraft frequently will result in a cancellation of the following trip on which the equipment was supposed to depart. However, because of considerations similar to those discussed above for delays, the outbound trip won't always be cancelled. In this study it was estimated that one-half of diversions result in subsequent cancellations. This estimate is consistent with fragmentary information obtained from a couple of airlines. A similar estimate was made with respect to aircraft that cancel because of below-minimum forecasts for the destination airport. If the diversion or cancellation is caused by an overflight and the aircraft continues on to its next destination, there are no subsequent effects.

2. Air Taxi

Air taxi and commuter airlines operate in much the same manner as the certificated route air carriers but on a lesser scale. Operations are conducted with smaller aircraft and fewer passengers (an average of 6.3) are carried per flight. Stage lengths average 100 miles, roughly one-half hour's flying time, and fares run 15 to 20 cents per passenger mile (References 4, 11).

Little data exists about the behavior of air taxi aircraft operators when faced with weather-caused flight disruptions, or about the distribution of such disruptions. The distribution of air taxi aircraft flight disruptions probably is similar to that found for certificated route air carriers operating into nonhub airports. Because of the shorter stage lengths, however, and the greater availability of alternative means of transportation, delays associated with diversions and cancellations are less severe. For purpose of this report, it is estimated that the impact of delays on air taxi aircraft and passengers is similar to that experienced by the certificated route air carriers at nonhub airports, but that diversions and cancellations have only one-half the impact. When flights are cancelled, an estimated 70 percent of the potential air taxi passengers will cancel their trips or use another means of travel.

3. General Aviation

Most flight disruptions due to weather in general aviation are borne by business travelers flying in relatively large aircraft equipped for IFR operations. The pattern of flight disruptions experienced in general aviation probably is similar to that estimated for the trunk air carriers, except that there are few secondary effects of flight disruptions in general aviation. The impact of flight disruptions on passengers is less because the aircraft they are traveling in is available for use as soon as the weather clears. Because of the greater number of airports that they can operate into, diversion times are less. Some interrupted trip expenses will be incurred for meals and overnight accommodations in some cases; these are estimated to average $15 per diverted passenger and $5 per cancelled passenger.

4. Summary of Flight Disruption Effects

Flight disruption effects are summarized in Table A-1 by type of disruption and aviation category. These effects are costed out in the following section.

Costs of Flight Disruptions

1. Air Carrier

The Civil Aeronautics Board publishes detailed statistics on air carrier aircraft operating costs and performance (Reference 10). One breakdown gives flying operations cost per block hour by type of aircraft for the domestic operations of domestic trunk airlines and for the local service airlines. Flying operations costs include crew, fuel and oil, insurance, and maintenance; depreciation costs are excluded. The latest published data is for CY-1973. Since then, fuel costs have doubled. Making that adjustment, the average hourly operations cost for domestic trunk aircraft is about $800 and for local service aircraft it is $425.

The other major cost factor used in this analysis is the value of passenger time lost, estimated at $12.50 an hour. This estimate is a combination of projected data developed by United Research, Inc. (Reference 6) and other related studies by consultants in the aviation field.

A number of letter symbols and subscripts are used in the cost estimating equations derived in the remainder of this section. Most of these fall out when equations are combined and do not reappear. For the convenience of readers who wish to follow the development of the individual equations, these symbols and subscripts are listed below:

C - cost	H - hub airport
DL - delay	N - nonhub airport
DV - diversion	A - air carrier
CL - cancellation	T - air taxi
O - overflight	G - general aviation

TABLE A-1

Summary of Flight Disruption Effects

Flight Disruption Effect	Hub Airport	Nonhub Airport	Air Taxi	General Aviation
Extra Aircraft Flight Time (Hours)				
Delays				
Primary*	3/8	3/8	3/8	3/8
Queue Reduction	1/2	---	---	---
Total	7/8	3/8	3/8	3/8
Diversions				
Primary	1	1	1/2	1/2
Repositioning Aircraft	1/2	1/2	1/4	---
Total	1-1/2	1-1/2	3/4	1/2
Cancellations				
Repositioning Aircraft	1/6	1/6	---	---
Passenger Time Lost (Hours)				
Delays				
Primary	3/4	3/4	3/4	3/4
Queue Reduction	1/2	---	---	---
Secondary	3/4	3/4	3/4	---
Total	2	1-1/2	1-1/2	3/4
Diversions				
Primary	5	5	2-1/2	2-1/2
Secondary	2-1/2	2-1/2	1-1/4	---
Total	7-1/2	7-1/2	3-3/4	2-1/2
Cancellations				
Primary	4	4	2	2
Secondary	2	2	1	---
Total	6	6	3	2
Overflights				
Diverted Passengers	---	5	2-1/2	---
Cancelled Passengers	---	4	2	---
Passenger Handling Expense				
Delays	$--	$--	$--	$--
Diversions	30	10	15	15
Cancellations	10	10	5	5
Revenue Loss Due to Cancellations	20%	20%	70%	---

*An estimated 50% of aircraft delay is taken on the ground at the departure airport.

For example, the symbol C_{DL-AH} represents the cost of delaying an air carrier aircraft at a hub airport.

Delay Costs

a. Hub Airports. Airline delay costs equal 50 percent of 45 minutes per delayed aircraft plus 30 minutes for queue reduction, at $800 per hour, or $700 per delayed aircraft.

Passenger delays, primary plus secondary effects, equal 2 hours per passenger (45 minutes of weather delay plus 30 minutes' queue reduction plus 45 minutes' secondary effects). At $12.50 an hour, this equals $25 per passenger which, when multipled by the number of passengers (n) deplaning*, gives the total cost of passenger delay time. The total cost per delayed air carrier aircraft at hub airports (C_{DL-AH}) thus is estimated to be:

$$C_{DL-AH} = \$25n + \$700$$

where n = number of deplaning passengers.

The above procedure does not allow for delays to passengers continuing their trips on the delayed aircraft. The average airline passenger trip includes two landings, i.e., only about one-half of the passengers disembark at a given stop. The proportion disembarking will be higher at major airports, of course, and lower at small airports. This factor has been omitted from the estimates of delay costs at hub airports; it is reflected, however, in the estimates of delay costs at nonhub airports.

b. Nonhub Airports. Fifty percent of 45 minutes per delayed aircraft, at $425 an hour, equals $159 per delayed aircraft.

*Deplaning passengers equal enplaning passengers on the average. Average numbers of enplaned passengers per departure can be derived from data published in Airport Activity Statistics of the Certificated Route Air Carriers (Reference 3).

Cumulative delays of 1½ hours per passenger at $12.50 per hour equals $18.75 per delayed passenger. At least one-half and usually more of the passengers on a flight into a small airport are through passengers, i.e., they remain on the aircraft; these passengers will also be delayed, of course. To account for this factor in total passenger delay costs, multiply the number of deplaning passengers by 2 and the product by $18.75 per delayed passenger. The total cost per delayed passenger at nonhub airports (C_{DL-AN}) is then:

$$C_{DL-AN} = 2(\$18.75)n + \$159$$

$$= \$37.50n + \$159$$

where n is the number of deplaning passengers.

Cancellation Costs

a. Hub Airports

Per aircraft

Repositioning aircraft (1/6 of $800)	$ 133.33
Less direct operating savings (1.25 hours @ $800)	(1,000.00)
Total	$ 866.67

Per passenger

Extra handling expense	$ 10.00
Revenue loss	70.00
Less revenue recovered (at 80%)	(56.00)
Lost time (4 hours @ $12.50)	50.00
Total	$ 74.00

One-half of the cancellations lead to subsequent cancellations, so the costs associated with an air carrier cancellation at a hub airport (C_{CL-AH}) are:

$$C_{CL-AH} = 1\text{-}1/2(\$74.00n - \$866.67)$$

$$= \$111n - \$1300$$

where n is the number of deplaning passengers.

b. Nonhub Airports

Per aircraft

Repositioning aircraft	$ 70.83
Less direct operating savings (0.58 hour at $425)	(246.50)
Total	($175.67)

Per passenger

Extra handling expense	$ 10.00
Revenue loss	70.00
Less revenue recovered (at 80%)	(56.00)
Lost time (4 hours at $12.50)	50.00
Total	$ 74.00

Since one-half of these cancellations are expected to lead to subsequent cancellations, the total costs associated with an air carrier cancellation at a non-hub airport (C_{CL-AN}) are:

$$C_{CL-AN} = 1\text{-}1/2\ (\$74.00n - \$175.67)$$

$$= \$111n - \$263$$

where n is the number of deplaning passengers.

Diversion Costs

a. Hub Airports

Per aircraft

In-flight delays (1 hour @ $800)	$ 800.00
Repositioning aircraft (1/2 hour @ $800)	400.00
Total	$1,200.00

Per passenger

Extra handling expense	$ 30.00
Lost time (5 hours @ $12.50)	62.50
Total	$ 92.50

Estimating that one-half of all diversions lead to subsequent cancellations, we have as the cost of an air carrier aircraft diversion from a hub airport (C_{DV-AH}):

$$C_{DV-AH} = \$92.50n + \$1,200 + 1/2(\$111n - \$1,300)$$

$$= \$148n + \$550$$

where n is the number of deplaning passengers.

b. <u>Nonhub Airports</u>

Per aircraft

In-flight delays (1 hour @ $4.25)	$425.00
Repositioning aircraft (1/2 hour @ $425)	212.50
Total	$637.50

Per passenger

Extra handling expense	$ 30.00
Time lost (5 hours @ $12.50)	62.50
Total	$ 92.50

If one-half of these diversions lead to subsequent cancellations, we have for the costs associated with the diversion of an air carrier aircraft from a non-hub airport (C_{DV-AN}) the following:

$$C_{DV-AN} = \$92.50n + \$637.50 + 1/2(\$111n - \$263)$$

$$= \$148n + \$506$$

where n is the number of deplaning passengers.

Overflight Costs. Overflight costs apply at nonhub airports only. No aircraft operating costs are included and there are no subsequent effects of overflights. Passenger costs associated with an overflight included:

Diverted passengers

Passenger handling expenses	$30.00
Lost time (5 hours @ $12.50)	62.50
Total	$92.50

Cancelled passengers

Passenger handling expense	$10.00
Lost time (4 hours @ $12.50)	50.00
Revenue loss	70.00
Less revenue recovered (at 80%)	(56.00)
Total	$74.00

The total cost of an overflight (C_O) thus is:

$$C_O = n(\$92.50 + \$74)$$

$$= \$166.50n$$

where n is the number of passengers.

Summary Air Carrier Flight Disruption Costs. Total estimated costs associated with weather-caused disruption of air carrier flights can now be determined by weighing the cost of each type of disruption by its proportional frequency of occurrence and combining costs, as follows:

a. Hub Airports

Disruption	Cost Equation	Weight
Delays	$ 25n + $ 700	0.75
Cancellations	111n - 1,300	.20
Diversions	148n + 550	.05
All Disruptions	$48.35n + $293	1.00

The average cost of air carrier flight disruptions at hub airports (C_{A-H}) thus is estimated to be:

$$C_{A-H} = \$48n + \$293$$

where n is the number of deplaning passengers.

If the approach-and-landing aid under consideration is one used by large aircraft only, as in the case of the Category IIIA ILS, aircraft operating costs used in the cost estimating equations should be adjusted accordingly.

b. Nonhub Airports

Disruption	Cost Equation	Weight
Delays	\$ 37.50n + \$159.00	0.48
Cancellations	111.00n - 263.00	.12
Diversions	148.00n + 506.00	.03
Overflights	166.50n	.37
All Disruptions	\$ 97.37n + \$ 60.00	1.00

So for the average cost of air carrier flight disruptions at nonhub airports(C_{A-N}) we have:

$$C_{A-N} = \$97n + \$60$$

where n is the number of enplaned passengers.

2. Air Taxi

Based on data published in References 4 and 11, flying operations costs for air taxi aircraft (excluding depreciation) are estimated to approximate \$60 an hour Passenger fares average \$17.25 per trip, and it is estimated that only 30 percent of this potential revenue is recovered when a trip is cancelled. Air taxis are subject to the same kinds of flight disruptions as the certificated route carriers but, because of the shorter stage lengths flown, the effects of cancellations and diversions are estimated to be only one-half as severe. No distinction is made between air taxi flight disruptions at hub and nonhub airports. It is estimated that extra handling expenses average $15 per diverted passenger and $5 for cancelled passenger. The value of air taxi passenger time lost due to weather-caused flight disruptions is set at $12.50 per hour. Applying the above factors, where appropriate, to the flight disruption effects developed earlier yields the following estimates of the costs of air taxi flight disruptions.

Delay Costs. Air taxi aircraft delay costs average 3/8 of an hour per delay at $60 an hour, or $22.50 per delay. Passengers are delayed an estimated 1½ hours each on the average, including secondary effects, at a cost of $18.75. The total cost per delayed air taxi aircraft (C_{DL-T}) is thus estimated to be:

$$C_{DL-T} = \$18.75n + \$22.50$$

where n is the number of deplaning passengers.

Cancellation Costs. The cancellation of an air taxi flight saves the cost of operating the aircraft (½ hour at $60 equals $30). Estimated costs per cancelled passenger are:

Extra handling expense	$ 5.00
Passenger time lost (3 hours @ $12.50)	37.50
Revenue loss	17.25
Less revenue recovered (at 30%)	(5.18)
Total	$54.57

The effects of subsequent cancellations have been reflected in the average time lost per passenger, so we have as the average cost of an air taxi cancellation (C_{CL-T}):

$$C_{CL-T} = \$54.57n - \$30.00$$

where n is the number of deplaning passengers.

Diversion Costs. An additional 3/4 hour aircraft operating time costs $45. Passenger costs include $15 extra handling expense plus 3-3/4 hours (including secondary effects) of passenger time lost at $12.50 an hour, for a total of $61.88 per passenger. Total estimated air taxi diversion costs (C_{DV-T}) are:

$$C_{DV-T} = \$61.88n + \$45.00$$

where n is the number of deplaning passengers.

Overflight Costs

Per cancelled passenger

Extra handling cost	$ 5.00
Time lost (2 hours @ $12.50)	25.00
Revenue loss	17.25
Less revenue recovered (at 30%)	(5.18)
Total	$42.07

Per diverted passenger

Extra handling expense	$15.00
Time lost (2-1/2 hours @ $12.50)	31.25
Total	$46.25

$$C_{O-T} = n(\$42.07 + \$46.25) = \$88.32n$$

where n is the number of enplaned passengers.

Summary Air Taxi Flight Disruption Costs. Weighing each kind of air taxi flight disruption cost by the distribution of flight disruptions found to apply at nonhub airports gives:

Disruption	Cost Equation	Weight
Delays	\$18.75n + \$22.50	0.48
Cancellations	54.57n - 30.00	.12
Diversions	61.88n + 45.00	.03
Overflights	88.32n	.37
All Disruptions	\$50.08n + \$ 8.55	1.00

The average cost of a weather-caused air taxi flight disruption (C_T) therefore is estimated to be:

$$C_T = \$50n + \$9$$

where n is the number of deplaning passengers.

3. General Aviation

As was noted earlier, most flight disruptions due to weather in general aviation are borne by business travelers flying in relatively large aircraft equipped for IFR operations. Flying operations costs for this type of aircraft are estimated at \$40 an hour or roughly equivalent to those of a light twin aircraft. Interrupted trip expenses were estimated to approximate \$15 per diverted passenger and \$5 per cancelled passenger. There are few secondary effects of general aviation flight disruptions, and no distinction has been made between general aviation flight disruptions at hub and nonhub airports.

Delay Costs. An extra 3/8 hour's flying time was assumed to apply to the average general aviation aircraft delay. At \$40 an hour, this equals \$15 per delay. Passenger delays average 3/4 hour at \$12.50 per hour, or \$9.38. Total costs of general aviation delays (C_{DL-G}) due to weather thus average:

$$C_{DL-G} = \$9.38n + \$15$$

where n is the number of persons on board.

Cancellation Costs. No additional aircraft flying time is involved. Passenger costs average $5 extra handling expense plus 2 hours' delay at $12.50 an hour for a total of $30.

$$C_{CL-G} = \$30n$$

where n is the number of persons on board.

Diversion Costs

Per aircraft	
1/2 hour's extra flying time @ $40	$20.00
Per passenger	
Extra handling expense	$15.00
2-1/2 hours' delay @ $12.50	31.25
Total	$46.25

$$C_{VD-G} = \$46.25n + \$20$$

where n is the number of persons on board.

Summary of General Aviation Flight Disruption Costs. Weighing general aviation flight disruption costs by their expected frequency of occurrence we have:

Disruption	Costs Equation	Weight
Delays	$ 9.38n + $15	0.75
Cancellations	30.00n	.20
Diversions	46.25n + 20	.05
All Disruptions	$15.35n + $12	1.00

Summary of Weather-Caused Flight Disruption Costs. Recapitulating, we have for the average costs of flight disruptions:

Air Carrier	
Hub airport	$48n + $293
Nonhub airport	97n + 60
Air Taxi	50n + 9
General Aviation	15n + 12

where n is the number of deplaning passengers.

Numbers of passengers is a variable in all of these equations. Actual data should be used to estimate the costs of flight disruptions if it is available. For broad planning purposes, we can estimate the average number of passengers deplaning each type of flight and convert the cost equations to average dollar values, as follows:

Type of Flight	Average Number of Deplaning Passengers*	Average Cost per Flight Disruption
Air Carrier		
Large hub	54.0	$2,885
Medium hub	38.1	2,120
Small hub	29.7	1,720
Nonhub	8.1	845
Air Taxi	6.3	325
General Aviation	5.0	90

*Average number of deplaning air carrier passengers derived from CAB/FAA Airport Activity Statistics (Reference 3); air taxi passengers from CAB Commuter Air Carrier Traffic Statistics (Reference 4); passengers, including crew, aboard general aviation IFR flights estimated from itinerant flight survey data.

APPENDIX B

SAFETY BENEFITS

Simpson (Reference 12) recently completed a detailed analysis of civil aviation accidents between January 1964 and December 1972. One section of his report covered landing accidents and, in particular, he searched the entire NTSB data base for accidents which happened under circumstances where it could be hypothesized that at least some of the accidents might have been avoided if precision approach facilities had been available and used. The benefits of preventable landing accidents developed in this appendix are based on Simpson's statistics.

During the period January 1964 through December 1972, there were 18,602 landing accidents resulting in 1,627 fatalities within the conterminous 48 United States under "normal" operating conditions (i.e., excluding abnormal operating conditions such as impaired pilot and aircraft failure or malfunction). These accidents were categorized by Simpson as instrument approach accidents, visual approach accidents, and runway accidents (Figure B-1). Numbers of accidents and fatalities within each of the categories between 1964 and 1972 are shown by user class in Table B-1.

TABLE B-1

Landing Accidents and Fatalities
by Type of Accident and User Class
48 Conterminous States
January 1964 - December 1972

	Landing Accidents/Fatalities			
Accident Category	Air Carrier	Air Taxi	General Aviation	Total
Instrument Approach				
Precision	22/86	19/6	67/70	108/162
Nonprecision	13/166	21/49	123/121	157/336
Visual Approach	54/300	287/32	11,048/786	11,389/1,118
Runway	35/0	117/0	6,796/11	6,948/11
Total	124/552	444/97	18,034/988	18,602/1,627

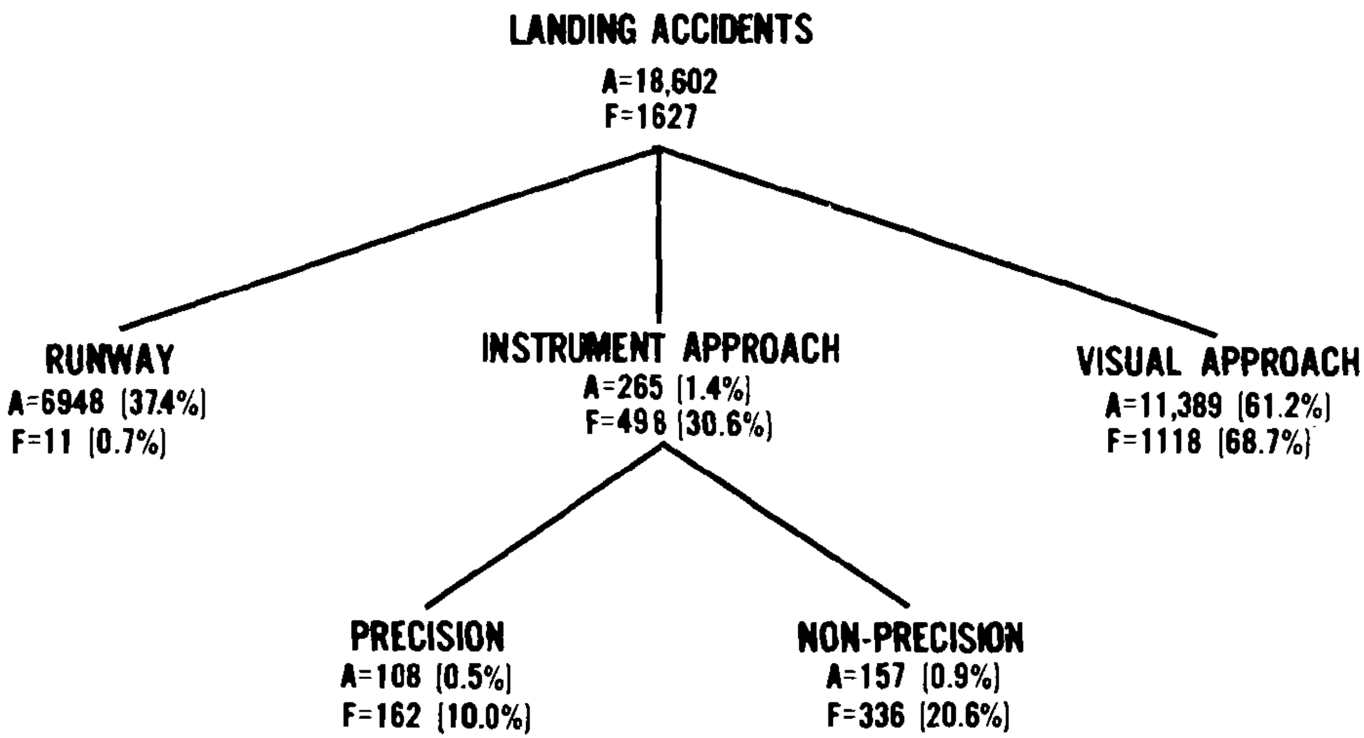

FIGURE B-1. -- LANDING ACCIDENTS WITHIN THE CONTERMINOUS UNITED STATES

JANUARY 1964 - DECEMBER 1972

Benefits of preventable instrument approach accidents are estimated for each major user group. This category of accident includes those that occurred while on a circling approach in IFR weather, i.e., certain visual approach accidents, as well as nonprecision approach accidents. Only those accidents judged to have been possibly avoidable with an ILS were included in the benefit calculations.

Benefits of preventable VFR visual approach accidents and runway accidents, two other important landing accident categories, have been estimated for general aviation but not for air carrier or air taxi. This was done because nominally preventable general aviation landing accidents of these kinds represent a significant proportion of total general aviation aircraft accidents and fatalities. For air carrier and air taxi aircraft this category of accident is relatively less important.

Substantial benefit credit has been given for potentially preventable accidents despite the fact that some of these accidents might have occurred if better guidance information had been available. This was done for two reasons. First, the benefit analysis has been limited to those accidents that have been judged as being possibly avoidable had better approach-and-landing aids been available.

The second and perhaps more important reason is a risk avoidance argument. Utility theory holds that decision makers will invest a dollar with the knowledge that less than a dollar will be returned if they wish to avoid potential adverse consequences, i.e., if they are risk avoiders. There is evidence that Congress and the public are risk avoiders with respect to aviation safety, that in their eyes safety benefits weigh more heavily than economic benefits. Investments in landing aids are a form of insurance against potentially disastrous accidents and, as such, conform both to public sentiment and to FAA policy, which places safety above all other considerations.

This reasoning also pertains to the present Airway Planning Standard criterion which states that "An airport where scheduled air carrier turbojet operations are conducted on a sustained basis...is a candidate for a Category I ILS with an approach light system..." Proper alignment on approach is especially critical with large turbojet aircraft because of their size, speed, and relatively slow response times. The National Transportation Safety Board has recommended that some sort of vertical guidance, ILS or VASI, be provided on all runways serving air carrier jet aircraft. For these reasons, and because of the high costs of air carrier accidents, the air carrier jet-use criterion for ILS has been retained.

Costs of IFR Landing Accidents Partially Avoidable by Precision Approach Facilities

As part of his analysis of aircraft accident data, Simpson (Reference 12) searched the entire NTSB Data Base for accidents which happened under circumstances where it could be hypothesized that at least some of the accidents might have been avoided if precision approach facilities had been available and used. Specifically, the NTSB Data Base was searched for accidents which involved any one of the following conditions:

1. An undershoot and crash while on final approach in IFR weather;

2. Crashed after executing a missed approach in IFR weather;

3. Crashed while on a circling approach in IFR weather.

Two other types of accidents, overshoots and stalls, were also investigated to find out if they might have been prevented by a precision approach, but an initial analysis indicates that they probably could not have been.

The total number of accidents and fatalities occurring during visual and nonprecision instrument approaches under one of the three conditions identified above are shown in Table B-2.

TABLE B-2

Landing Accidents under Instrument Approach Conditions
That Might Have Been Prevented by a Precision Approach Aid
by User Group, Conterminous United States
1964 through 1972

User Group	Accidents	Fatalities	Fatalities/ Accidents
Air Carrier	6	48	8.0
Nonprecision Approach	6	48	8.0
Air Taxi	25	49	2.0
Nonprecision Approach	20	43	2.2
Visual Approach	5	6	1.2
General Aviation	117	111	0.9
Nonprecision Approach	55	79	1.4
Visual Approach	62	32	.5

Estimates of the safety benefits provided by an ILS through the prevention of IFR approach accidents have been estimated by, first, converting the number of accidents and fatalities given above into accident rates and, second, estimating accident costs. Multiplying accident costs by the probability of an accident (or dividing by the average number of approaches between accidents) gives a measure of the benefit provided by a precision approach aid through prevention of this kind of accident.

Determining the probability of a nonprecision approach accident requires some knowledge of the number of nonprecision approaches that were made. The FAA records total instrument approaches by airport and user group but does not distinguish between precision and nonprecision approaches. However, proportionate precision and nonprecision approaches can be estimated by examining the distributions of instrument approaches by airport type. This data for CY-1973 is given in Table B-3.

TABLE B-3

Instrument Approaches by Hub Type*
and Civil User Group
CY-1973

Hub Type	Instrument Approaches (Thousands)					
	Air Carrier		Air Taxi		General Aviation	
	No.	%	No.	%	No.	%
Large	442	51.6	50	30.5	78	11.0
Medium	177	20.7	19	11.6	95	13.4
Small	125	14.6	23	14.0	130	18.4
Nonhub	112	13.1	72	43.9	404	57.2
Total	856	100.0	164	100.0	707	100.0

* Hub classification is determined by an airport's percentage of total enplaned revenue passengers by the certificated route air carriers.

All hub airports but one are equipped with ILS, as are a number of nonhub airports. Large- and medium-hub airports usually have multiple ILS's. Bearing in mind that an instrument approach is counted only if the aircraft is on an IFR flight plan and IFR weather conditions prevail, it is estimated that the following proportions of instrument approaches were precision approaches in FY-1973: Large-hub airports - 90 percent; medium-hub airports - 75 percent; small-hub airports - 60 percent; nonhub airports - 20 percent. Applying these percentages to the numbers of instrument approaches in Table B-3 gives the following proportions of precision and nonprecision approaches by user group in 1973 (the general aviation percentages have been adjusted by 10 percent to allow for the fact that not all general aviation aircraft flying IFR are ILS-equipped):

User Group	Precision Approaches	Nonprecision Approaches
Air Carrier	73%	27%
Air Taxi	53%	47%
General Aviation	38%	62%

About one-fourth fewer ILS's were operational during the 1964-1972 period than in 1973, although all high-density airports were well-equipped. For the computation of accident rates during 1964-1972, therefore, the preceding nonprecision approach percentages have been increased to: Air carrier - 30 percent; air taxi - 50 percent; general aviation - 65 percent.

Nonprecision approach accident rates are developed in Table B-4. For the period from 1964 through 1972, total instrument approaches by user group were taken from FAA Air Traffic Activity Reports. Air taxi instrument approaches were not counted separately prior to 1972. In that year and in 1973 air taxi represented about 19 percent of the combined total of air taxi plus general aviation instrument approaches. On that basis, air taxi instrument approaches were estimated to be 19 percent of the general aviation total for the years 1964 through 1971.

TABLE B-4

Preventable Nonprecision Approach Accident Rates
by User Group
1964-1972

User Group	Total Instrument Approaches 1964-1972	Nonprecision Approaches		Preventable Nonprecision Approach Accidents*	Approaches per Accident
		Percent	Number		
Air Carrier	7,094,000	30	2,128,000	6	355,000
Air Taxi	810,000	50	405,000	25	16,000
General Aviation	3,454,000	65	2,245,000	117	19,000

*From Table B-2

Accident costs include loss or damage to property and loss or injury to human life. Aircraft replacement costs average about $6,000,000 for air carrier aircraft, $200,000 for air taxi aircraft, and $50,000 for general aviation aircraft. As nonprecision approach accidents often result in total destruction of the aircraft, it is estimated that loss or damage to aircraft averages 90 percent of replacement cost in these instances.

Aircraft accident fatalities have been costed at $300,000 each. This estimate was based on values developed by FAA's Office of Aviation Policy and Plans for use in benefit/cost studies. The basic data was obtained from the Civil Aeronautics Board and is based on non-Warsaw payments during the period 1966 to 1970, projected from the base period to 1975.

Estimated nonprecision approach accident costs are shown in Table B-5. The value of lives lost was determined by multiplying the value of a life ($300,000) by the average fatalities per accident given in Table B-2. As data on number of injuries in accidents of this kind is not readily available, this factor has been omitted; accident costs are underestimated to that extent.

TABLE B-5

Average Costs of
Preventable Nonprecision Approach Accidents
by User Group
FY-1975

User Group	Aircraft Losses	Value of Lives Lost	Average Costs per Accident
Air Carrier	$5,400,000	$2,400,000	$7,800,000
Air Taxi	180,000	600,000	780,000
General Aviation	45,000	270,000	315,000

Dividing accident costs from Table B-5 by average numbers of approaches between accidents from Table B-4 gives the average "risk cost" per nonprecision approach. This cost is a measure of the benefit that a precision approach aid could provide by preventing accidents of this type. These benefits are given in Table B-6.

TABLE B-6

Benefits of Preventing Nonprecision Approach Accidents by User Group

User Group	Approaches per Accident	Average Costs per accident	Potential Benefits per Precision Approach
Air Carrier	355,000	$7,800,000	$22
Air Taxi	16,000	780,000	49
General Aviation	19,000	315,000	17

The air carrier safety benefits in Table B-6 are averaged for all preventable accidents, regardless of aircraft size or numbers of passengers aboard. The effects of these two factors can be approximated by proportioning air carrier safety benefits to the costs of air carrier flight disruptions developed in Appendix A, which reflect airport size and activity, as follows:

Hub Type	Costs of Air Carrier Flight Disruptions: Dollars	Costs of Air Carrier Flight Disruptions: Ratio to Average	Benefit per Preventable Air Carrier Approach Accident
Large	$2,885	1.52	$33
Medium	2,120	1.12	25
Small	1,720	.91	20
Nonhub	845	.45	10
Average	$1,892	1.00	$22

Costs of Preventable General Aviation VFR Accidents

As part of his analysis of accident data, Simpson (Reference 12) also made a preliminary sorting (without a manual analysis) of the 10,813 small general aviation accidents that occurred during a visual approach. Of these, 1,681 accidents with

185 fatalities were undershoots on final approach, and 306 accidents with 5 fatalities were collisions with ground, water, or an object while the aircraft was flaring. Simpson hypothesized that some part of such accidents might have been avoided if a visual glide slope such as that provided by a VASI had been available; similar guidance is given by an ILS if the aircraft is ILS-eauipped. At $300,000 per fatality and $25,000 aircraft damange per accident (50 percent of a replacement cost of $50,000), total costs of these accidents over the 9-year period approximated $107 million, in 1975 dollars.

Another 6,684 runway accidents were sustained by small general aviation aircraft during the study period. Accidents of this kind often are due to the pilot's failure to align his aircraft properly with the runway during final approach. Vertical guidance during the approach, given by either an ILS or a VASI, would help the pilot keep the aircraft on the proper glide path and set up a stabilized approach. Runway accidents seldom are as serious as approach accidents; the 6,684 general aviation accidents between 1964 and 1972 resulted in only 11 fatalities. By definition, however, all of these aircraft suffered substantial or greater damage. At an average cost of $2,500, repair of these aircraft cost about $17 million. Total costs of VFR general aviation landing accidents between 1964 and 1972 thus approximated $125 million, in 1975 dollars.

General aviation pilots made some 75 million itinerant and 87 million local landings at FAA tower airports between 1964 and 1972. Perhaps another 50 percent were made at nontower airports, for a total of some 250 million landings. Dividing the $125 million cost by 250 million landings gives a "risk cost" of about $0.50 per landing.

The benefit of an ILS or VASI in preventing general aviation VFR landing accidents, therefore, is 50 cents per landing. This benefit should be applied only to VFR aircraft on itinerant flights. Pilots doing local pattern work usually approach the runway at a steeper angle than that defined by the ILS or VASI.

Air carrier, air taxi, and large general aviation aircraft of the corporate/executive type also occasionally have accidents of these kinds. Such accidents typically are of relatively minor importance, however, and their costs have not been estimated here.

Summary of Safety Benefits

The benefit of an ILS (or VASI) in preventing general aviation VFR landing accidents is estimated to approximate $0.50 per itinerant aircraft landing. FAA statistics show that about one-fourth of the general aviation fleet is equipped with glide slope. If the pilots of these aircraft use the glide slope while making VFR approaches, the benefit of an ILS for the prevention of VFR landing accidents is about 12 cents per itinerant landing, averaged for all itinerant landings.

General aviation pilots made 722,000 instrument approaches in FY-1974, and it is estimated that they made about 18 million itinerant landings that year, 12 million at FAA tower airports and perhaps half as many at nontower airports. The ratio of itinerant landings to instrument approaches thus was about 25-to-1. Using this estimate, we can combine total ILS safety benefits into a single estimate for each user group in a manner that relates these benefits to benefits per instrument approach, as follows:

User Category	Benefits of Preventable: IFR Approach Accidents	VFR Landing Accidents	Total Safety Benefits per IFR Approach
Air Carrier			
Large Hub	$33	$*	$33
Medium Hub	25	*	25
Small Hub	20	*	20
Nonhub	10	*	10
Air Taxi	49	*	49
General Aviation	17	3	20

*Estimated to amount to 1 percent or less of the benefits of preventable IFR approach accidents.

To determine the total safety benefits provided by an ILS, multiply the number of instrument approaches expected to be made with the ILS by the benefit per approach.

APPENDIX C

SOURCES OF WEATHER DATA

Percentages of hourly weather observations falling within specified ceiling-visibility categories have been tabulated for the FAA by the National Climatic Center at Asheville, North Carolina, for the 271 airports listed at the end of this appendix. Data for any of the 271 airports will be furnished on request by ASP-110. More detailed data for the airports is available on magnetic tape.

This data in the report is in the following format:

STATION#14944 SIOUX FALLS, S. D. PERIOD OF RECORD 1/48-12/64

HOUR GROUP	NO.OF OBS	CEILING-VISIBILITY CATEGORIES (%) (1)	(2)	(3)	(4)	(5)	(6)	SYSTEM ENHANCEMENT FACTORS (%) VOR	CAT1	CAT2	MIN*
JAN ALL	12646	82.8	17.2	12.7	2.8	0.9	0.9	73.8	16.1	5.0	5.0
FEB "	11542	79.4	20.6	14.9	2.9	1.0	1.8	72.3	14.2	4.9	8.6
MAR "	12645	80.2	19.8	15.0	2.9	0.8	1.1	75.8	14.6	3.9	5.7
APR "	12236	87.5	12.5	11.1	1.1	0.2	0.2	89.0	8.4	1.2	1.4
MAY "	12647	89.4	10.6	9.7	0.8	0.1	0.0	91.1	7.6	0.9	0.4
JUN "	12239	92.6	7.4	6.8	0.5	0.1	0.1	91.2	6.3	1.2	1.3
JUL "	12647	95.3	4.7	4.2	0.3	0.1	0.1	89.8	5.4	2.4	2.4
AUG "	12648	93.6	6.4	5.2	0.9	0.1	0.2	81.7	13.4	2.0	3.0
SEP "	12239	91.3	8.7	7.3	0.7	0.2	0.4	84.4	8.3	2.6	4.6
OCT "	12646	90.0	10.0	8.1	0.9	0.4	0.7	81.0	8.6	3.7	6.7
NOV "	12237	87.4	12.6	9.7	1.4	0.6	0.9	76.9	11.0	4.9	7.2
DEC "	12647	79.8	20.2	15.4	2.8	1.0	1.1	76.3	13.6	4.7	5.3
ANN 07-13	43463	84.4	15.6	12.9	1.7	0.4	0.6	82.7	11.1	2.6	3.5
14-21	49676	90.4	9.6	8.1	1.0	0.2	0.2	84.7	11.0	2.0	2.3
22-06	55880	87.3	12.7	9.4	1.6	0.7	1.0	73.6	12.9	5.5	8.0
ALL	149019	87.5	12.5	10.0	1.5	0.4	0.6	79.8	11.8	3.6	4.9

CEILING VISIBILITY CONDITIONS (% OF TOTAL OBSERVATIONS)	SYSTEMS ENHANCEMENT FACTORS (CEILING VISIBILITY CONDITIONS)
(1) ≥ 1500 FEET AND 3 MILES	
(2) < 1500 FEET AND/OR 3 MILES	VOR=FREQ (3)/FREQ(2)
(3) < 1500 FEET AND/OR 3 MILES,BUT ≥ 400 FEET AND 1 MILE	CAT1 ILS=FREQ(4)/FREQ(2)
(4) < 400 FEET AND/OR 1 MILE, BUT ≥ 200 FEET AND 1/2 MILE	CAT2 ILS=FREQ(5)/FREQ(2)
(5) < 200 FEET AND/OR 1/2 MILE,BUT ≥100 FEET AND 1/4 MILE	*BELOW MINIMUMS=FREQ(6)/FREQ(2)
(6) < 100 FEET AND/OR 1/4 MILE	

To determine the increased IFR runway utilization to be expected with a new approach-and-landing aid, divide the percentage of instrument weather (defined herein as equal to or less than 1,500-feet ceiling and/or 3 miles visibility) in the category given by the new navaid by the percentage given by the old aid. In the example on the previous page, 11.5 percent (10.0 plus 1.5) of all observations were instrument approach weather better than Category I minimums (200-½) while 10.0 percent of the observations were better than VOR minimums (400-1). Therefore, if an ILS reduced minimums from 400-1 to 200-½, one would expect an increase of 15 percent (11.5/10.0 = 115%) in runway utilization during instrument weather conditions and a corresponding decrease in flight disruptions (delays, diversions, and cancellations).

Data for the 271 airports can be used directly if the weather categories of interest coincide with those published. If not, estimates can be interpolated from this and other weather data or actual data can be obtained from the basic detail information for each airport stored on magnetic tape. For those airports not on the list of 271, use the nearest airport for which data is available and at which weather patterns are similar.

To assist in interpolating for other than published weather categories, national averages of weather equal to or less than minimums of from 200-½ through 1500-3 are given in Table C-1. This data is based on averages of percentage distributions of hourly ceiling and visibility observations at 32 airports, representing in most cases 10 years of data from 1949 through 1958 (Reference 14).

TABLE C-1

Percentage Distributions of Weather Observations
Equal to or Less Than Selected Ceilings and/or Visibilities

Ceiling (Feet)	Visibility (Miles) 1/2	3/4	1	1-1/2	3
	%	%	%	%	%
200	1.12	1.52	2.01	3.13	7.10
300	1.48	1.79	2.21	3.25	7.13
400	2.14	2.37	2.73	3.64	7.29
500	2.88	3.08	3.38	4.20	7.60
600	3.67	3.84	4.09	4.81	7.99
700	4.57	4.72	4.95	5.60	8.57
800	5.47	5.61	5.81	6.40	9.15
1,000	7.24	7.36	7.54	8.05	10.48
1,500	10.80	10 91	11.05	11.45	13.48

In Table C-2, the data in Table C-1 is expressed as differences between 1500-3, usually the minimums below which instrument approaches are counted, and specified minimums. For example, on the average 13.48 percent of all weather observations are less than 1,500 feet ceiling and/or 3 miles visibility. For a nonprecision approach with minimums of 400-1, 2.73 percent of all observations, on the average, are equal to or less than 400 feet ceiling and/or 1 mile visibility. The difference between the two--13.48 minus 2.73 = 10.75--is the percentage of weather observations falling between minimums of 1500-3 and 400-1.

TABLE C-2

Percentage Distributions of Weather Observations
between Specified Minimums and 1500-3

Ceiling (Feet)	Visibility (Miles)				
	1/2	3/4	1	1-1/2	3
	%	%	%	%	%
200	12.36	11.96	11.47	10.35	6.38
300	12.00	11.69	11.27	10.23	6.35
400	11.34	11.11	10.75	9.84	6.19
500	10.60	10.40	10.10	9.28	5.88
600	9.81	9.64	9.39	8.67	5.49
700	8.91	8.76	8.53	7.88	4.91
800	8.01	7.87	7.67	7.08	4.33
1,000	6.24	6.12	5.94	5.43	3.00
1,500	2.68	2.57	2.43	2.03	0

Table C-3 gives the average increases in airport utilization associated with reductions from specified nonprecision approach minimums to ILS minimums (200-1). For example, from Table C-2 we find that 12.36 percent of all weather observations lie between 1500-3 and 200-½, and 10.75 percent lie between 1500-3 and 400-1. If an ILS permitted a reduction in minimums of from 400-1 to 200-½, we would expect an average 15 percent increase in runway utilization (12.36/10.75 = 115%). Similarly, if minimums were reduced from 800-1½ to 400-1, we would expect a 52 percent increase in runway utilization (10.75/7.08 = 1.52). In this way, the increased runway utilization associated with any change in approach minimums can be estimated.

TABLE C-3

Average Increases in Airport Utilization
Associated with Reductions in Approach Minimums
from Specified Values to ILS Minimums
(200 feet and/or ½ mile)

Ceiling (Feet)	Visibility (Miles)				
	1/2	3/4	1	1-1/2	3
	%	%	%	%	%
200	0	3.3	7.8	19.5	93.7
300	3.0	5.7	9.7	20.9	94.5
400	9.0	11.3	15.0	25.6	99.9
500	16.6	18.9	22.4	33.2	110.4
600	25.9	28.2	31.7	42.6	125.0
700	38.7	41.1	44.9	56.9	151.7
800	54.1	56.9	61.1	74.6	185.3
1,000	97.9	102.0	108.0	127.4	312.3
1,500	360.5	379.9	407.2	507.7	-

The data in Tables C-1 through C-3 is based on national averages. Weather patterns at individual airports may differ significantly from these averages, but the data in the above tables nevertheless is useful in interpolating between values published in the 271 airport weather report. For example, Sioux Falls, South Dakota, is a candidate for an ILS on Runway 21. That runway now has a localizer back course approach with minimums of 400-3/4. We saw in the tabulation on Page C-1 that at Sioux Falls a reduction in minimums of from 400-1 to 200-½ would increase airport utilization during instrument weather conditions by 11.5/10.0 = 1.15, or by 15 percent. No data is given for minimums of 400-3/4. Referring to Table C-3, however, we see that if lowering minimums 400-1 to 200-½ increases IFR airport utilization by 15.0 percent, a reduction from 400-3/4 to 200-½ can be expected to give an increase of 11.3 percent. In a similar manner, or by proportioning observed to average values, one can determine the expected increase in runway utilization associated with any reduction in minimums.

INDEX OF 271 AIRPORTS FOR WHICH WEATHER DATA IS AVAILABLE

Location	Airport	Lat. (N)	Long. (W)	Elev. (Ft.)	Page
ALABAMA					
Birmingham	Municipal	33:34	86:45	630	1
Dothan	Dothan	31:14	85:26	325	1
1) Huntsville	Municipal	34:42	86:35	606	2
Mobile	Bates	30:41	88:15	221	2
Montgomery	Dannelly	32:18	86:24	202	3
Muscle Shoals	Muscle Shoals	34:45	87:37	562	3
Tuscaloosa	Van de Graaff	33:14	87:37	186	4
ALASKA					
Anchorage	International	61:10	149:59	132	4
Anchorage	Merrill	61:13	149:50	132	5
Fairbanks	International	64:49	147:52	454	5
Juneau	Municipal	58:22	134:35	24	6
Kenai	Municipal	60:34	151:16	91	6
King Salmon	King Salmon	58:41	156:39	49	7
Kodiak	Municipal	57:44	152:31	112	7
ARIZONA					
Phoenix	Sky Harbor	33:26	112:01	1112	8
Tucson	International	32:07	110:56	2558	8
ARKANSAS					
Fort Smith	Municipal	35:20	94:22	463	9
Little Rock	Adams Field	34:44	92:14	265	9
Texarkana	Webb Field	33:27	94:00	368	10
CALIFORNIA					
Arcata		40:59	124:06	225	10
Bakersfield	Kern County	35:25	119:03	497	11
Burbank	Hollywood-Burbank	34:12	118:22	775	11
Chula Vista	Brown Field	32:24	116:58	525	12
Fresno	Air Terminal	36:46	119:43	330	12
Long Beach	Daugherty	33:49	118:09	40	13
Los Angeles	International	33:56	118:24	104	13
Monterey	NAF	36:35	121:52	164	14
Oakland	Metropolitan	37:44	122:12	7	14
Ontario	International	34:03	117:37	934	15
Sacramento	Executive	38:31	121:30	25	15
Salinas	Municipal	36:40	121:36	78	16
San Diego	Lindbergh Field	32:44	117:10	28	16
San Francisco	International	37:37	122:23	18	17
San Jose	Municipal	37:22	121:55	56	17
Santa Ana	Orange County	33:40	117:53	53	18
Santa Barbara	Municipal	34:26	119:50	20	18
Stockton	Metropolitan	37:54	121:15	27	19

Location	Airport	Lat. (N)	Long. (W)	Elev. (Ft.)	Page
COLORADO					
Colorado Springs	Peterson Field	38:49	104:42	6170	19
Denver	Stapleton Int'l.	39:45	104:52	5332	20
Grand Junction	Municipal	39:06	108:32	4839	20
Pueblo	Memorial	38:17	104:31	4639	21
CONNECTICUT					
Bridgeport	Municipal	41:10	73:08	25	21
Hartford	Bradley Int'l.	41:56	72:41	179	22
DELAWARE					
Wilmington	Greater	39:40	75:36	80	22
FLORIDA					
Daytona Beach	Regional	29:11	81:03	61	23
2) Fort Lauderdale	Fort Lauderdale-Hollywood Int'l.	26:04	80:09	8	23
Fort Myers	Page Field	26:34	81:52	20	24
3) Jacksonville	Imeson	30:30	81:42	31	24
Melbourne	Cape Kennedy Regional	28:06	80:38	28	25
Miami	International	25:48	80:16	12	25
Orlando	Herndon	28:33	81:20	119	26
2) Panama City	Bay County	30:12	85:41	20	26
Pensacola	Regional	30:28	87:12	118	27
2) Sarasota	Sarasota-Bradenton	27:24	82:33	24	27
Tallahassee	Dale Mabry	30:26	84:20	68	28
Tampa	International	27:58	82:32	11	28
West Palm Beach	International	26:41	80:06	21	29
GEORGIA					
Athens	Clarke County	33:57	83:19	801	29
Albany	Dougherty County	31:32	84:11	193	30
Atlanta	Hartsfield Int'l.	33:39	84:26	1034	30
Augusta	Bush	33:22	81:58	148	31
Columbus	Metropolitan	32:31	84:56	389	31
Macon	Lewis B. Wilson	32:42	83:39	362	32
Savannah	Travis Field	32:08	81:12	51	32
Valdosta	Municipal	30:47	83:17	216	33
HAWAII					
Hilo	Lyman Field	19:43	155:04	36	33
Honolulu	International	21:20	157:55	15	34
Kahului	Kahului	20:54	156:26	67	34
Lihue	Lihue	21:59	159:21	148	35

Location	Airport	Lat. (N)	Long. (W)	Elev. (Ft.)	Page
IDAHO					
Boise	Municipal	43:34	116:13	2868	35
Idaho Falls	Fanning Field	43:31	112:04	4744	36
Pocatello	Municipal	42:55	112:36	4454	36
ILLINOIS					
2) Champaign	Univ. of Illinois-Willard	40:02	88:17	777	37
Chicago	Midway	41:47	87:45	623	37
Chicago	O'Hare	41:59	87:54	674	38
Moline	Quad City	41:27	90:31	594	38
Peoria	Greater	40:40	89:41	662	39
Rockford	Greater	42:12	89:06	743	39
Springfield	Capital	39:50	89:40	613	40
INDIANA					
Evansville	Dress Regional	38:03	87:32	388	40
Fort Wayne	Baer Field	41:00	85:12	828	41
Indianapolis	Weir Cook	39:44	86:17	808	41
South Bend	St. Joseph County	41:42	86:19	773	42
Terre Haute	Hulman	39:27	87:18	593	42
West Lafayette	Purdue University	40:25	86:56	637	43
IOWA					
2) Cedar Rapids	Municipal	41:53	91:42	901	43
Des Moines	Municipal	41:32	93:39	963	44
Waterloo	Municipal	42:33	92:24	878	44
Sioux City	Municipal	42:24	96:23	1103	45
KANSAS					
Hutchinson	Hutchinson	38:04	97:52	1524	45
2) Salina	Salina	38:49	97:34	1275	46
Topeka	Municipal	39:04	95:38	885	46
Wichita	Municipal	37:39	97:25	1340	47
KENTUCKY					
Covington	(See Cincinnati)				
Lexington	Blue Grass	38:02	84:36	989	47
London	Corbin-London	37:05	84:05	1189	48
Louisville	Standiford	38:11	85:44	488	48
LOUISIANA					
Alexandria	Esler	31:23	92:18	118	49
Baton Rouge	Ryan	30:32	91:09	76	49
Lafayette	Municipal	30:12	91:59	42	50
Lake Charles	Municipal	30:07	93:13	14	50
Monroe	Municipal	32:31	92:03	81	51
New Orleans	Moisant	29:59	90:15	30	51
Shreveport	Regional	32:28	93:49	259	52

	Location	Airport	Lat. (N)	Long. (W)	Elev. (Ft.)	Page
	MAINE					
	Augusta	State	44:19	69:48	360	52
	Bangor	International	44:48	68:49	192	53
	Portland	Int'l. Jetport	43:39	70:19	63	53
	MARYLAND					
	Baltimore	Friendship	39:11	76:40	155	54
	Hagerstown	Municipal	39:42	77:43	704	54
	Salisbury	Wicomico County	38:20	75:30	60	55
	MASSACHUSETTS					
	Bedford	Hanscom	42:28	71:17	143	55
	Boston	Logan	42:22	71:02	29	56
	Nantucket	Memorial	41:15	70:04	12	56
2)	Westfield	Barnes	42:09	72:43	263	57
	Worcester	Municipal	42:16	71:52	986	57
	MICHIGAN					
	Battle Creek	Kellogg	42:18	85:14	939	58
	Detroit	City	42:25	83:01	626	58
	Detroit	Metropolitan	42:14	83:20	664	59
	Detroit	Willow Run	42:14	83:32	777	59
	Flint	Bishop	42:58	83:44	766	60
	Grand Rapids	Kent County	42:54	85:40	689	60
	Jackson	Reynolds	42:16	84:28	1020	61
2)	Kalamazoo	Municipal	42:17	85:36	955	61
	Lansing	Capital City	42:47	84:36	874	62
	Muskegon	County	43:10	86:14	633	62
	Saginaw	Tri-City	43:26	83:52	601	63
	Traverse City	Cherry Capital	44:44	85:35	630	63
	MINNESOTA					
	Duluth	International	46:50	92:11	1417	64
	Minneapolis	Minn.-St. Paul	44:53	93:13	838	64
	Rochester	Municipal	43:55	92:30	1297	65
	St. Paul	Holman Field (Downtown)	44:56	93:04	720	65
	MISSISSIPPI					
4)	Jackson	Municipal	32:20	90:13	332	66
	Meridian	Key Field	32:20	88:45	310	66
	MISSOURI					
5)	Kansas City	Municipal	39:07	94:36	750	67
	Springfield	Municipal	37:14	93:23	1270	67
	St. Joseph	Rosecrans Memorial	39:46	94:55	818	68
	St. Louis	Lambert	38:45	90:23	544	68

	Location	Airport	Lat. (N)	Long. (W)	Elev. (Ft.)	Page
	MONTANA					
	Billings	Logan Field	45:48	108:32	3570	69
	Great Falls	International	47:29	111:22	3657	69
	Helena	Municipal	46:36	112:00	3898	70
	Missoula	Johnson-Bell Field	46:55	114:05	3189	70
	NEBRASKA					
	Lincoln	Municipal	40:51	96:46	1169	71
	Omaha	Eppley	41:18	95:54	982	71
	NEVADA					
	Las Vegas	McCarran Int'l.	36:05	115:10	2162	72
	Reno	International	39:30	119:47	4400	72
	NEW JERSEY					
	Atlantic City	NAFEC-Pomona	39:27	74:34	67	73
	Newark	International	40:42	74:10	30	73
	Teterboro	Teterboro	40:51	74:03	7	74
	NEW MEXICO					
	Albuquerque	International	35:03	106:37	5314	74
	Farmington	Farmington	36:45	108:15	5509	75
	Hobbs	Lea County	32:41	103:12	3664	75
	Roswell	Air Center	33:18	104:32	3649	76
	NEW YORK					
	Albany	County	42:45	73:48	292	76
	Binghamton	Broome County	42:13	75:59	1629	77
	Buffalo	Greater	42:56	78:44	706	77
	Elmira	Chemung County	42:10	76:54	954	78
	Glen Falls	Warren County	43:20	73:37	71	78
2)	Islip	MacArthur	40:47	73:06	98	79
	New York	J. F. Kennedy	40:39	73:47	22	79
	New York	LaGuardia	40:46	73:54	31	80
	Niagara Falls	Municipal	43:06	78:57	625	80
	Poughkeepsie	Dutchess County	41:38	73:53	162	81
	Rochester	Rochester-Monroe County	43:07	77:40	555	81
	Syracuse	Hancock	43:07	76:07	408	82
2)	Utica	Oneida County-Oriskany	43:09	75:23	731	82
	White Plains	Westchester County	41:04	73:43	443	83

Location	Airport	Lat. (N)	Long. (W)	Elev. (Ft.)	Page
NORTH CAROLINA					
8) Asheville	Asheville	35:26	82:32	2140	83
Charlotte	Douglas	35:13	80:56	769	84
2) Fayetteville	Grannis	35:00	78:53	189	84
Greensboro	Greensboro-High Point	36:05	79:57	886	85
Raleigh	Raleigh-Durham	35:52	78:47	441	85
Wilmington	New Hanover County	34:16	77:55	38	86
Winston-Salem	Smith-Reynolds	36:07	80:12	995	86
NORTH DAKOTA					
Bismarck	Municipal	46:46	100:45	1660	87
Fargo	Hector	46:54	96:48	899	87
Grand Forks	International	47:55	97:05	832	88
OHIO					
Akron	Akron-Canton	40:55	81:26	1236	88
Cincinnati	Greater	39:04	84:40	877	89
Cleveland	Hopkins Int'l.	41:24	81:51	805	89
Columbus	Port Columbus	40:00	82:53	833	90
Dayton	J. M. Cox	39:54	84:13	1003	90
Mansfield	Lahm Municipal	40:49	82:31	1301	91
Toledo	Express	41:36	83:48	692	91
Youngstown	Municipal	41:16	80:40	1186	92
OKLAHOMA					
2) Lawton	Municipal	34:34	98:25	1108	92
Oklahoma City	Will Rogers	35:24	97:36	1304	93
Tulsa	International	36:12	95:54	676	93
OREGON					
Eugene	Mahlon Sweet Field	44:07	123:13	373	94
Klamath Falls	Kingsley	42:09	121:44	4102	94
Medford	Jackson County	42:22	122:52	1329	95
North Bend	Municipal	43:25	124:15	17	95
Pendleton	Pendleton Field	45:41	118:51	1482	96
Portland	International	45:36	122:36	39	96
Salem	McNary Field	44:55	123:00	209	97
PENNSLYVANIA					
Allentown	Allentown-Bethlehem-Easton	40:39	75:26	385	97
Bradford	Regional	41:48	78:38	2150	98
Erie	International	42:05	80:05	737	98
Franklin	Chess Lamberton	41:23	79:52	1540	99
Harrisburg	Harrisburg State	40:13	76:51	351	99
Middletown	Olmsted Field	40:12	76:46	318	100
Philadelphia	International	39:53	75:15	28	100
Philadelphia	North	40:05	75:01	119	101

Location	Airport	Lat. (N)	Long. (W)	Elev. (Ft.)	Page
Pittsburgh	Allegheny County	40:21	79:56	1273	101
Pittsburgh	Greater	40:30	80:13	1225	102
Wilkes-Barre	Wilkes-Barre-Scranton	41:20	75:44	948	102
Williamsport	Lycoming County	41:15	76:55	525	103
PUERTO RICO					
San Juan	Isle Verde	18:26	66:00	62	103
RHODE ISLAND					
Providence	T. F. Green	41:44	71:26	62	104
SOUTH CAROLINA					
Charleston	Municipal	32:54	80:02	48	104
Columbia	Metropolitan	33:57	81:07	225	105
6) Greenville	Municipal	34:51	82:21	1023	105
Florence	Municipal	34:11	79:43	148	106
Myrtle Beach	South	33:41	78:56	25	106
SOUTH DAKOTA					
Rapid City	Municipal	44:02	103:03	3168	107
Sioux Falls	Foss Field	43:34	96:44	1427	107
TENNESSEE					
Bristol	Tri City	36:29	82:24	1566	108
Chattanooga	Lovell	35:02	85:12	688	108
Knoxville	Municipal	35:49	82:24	980	109
Memphis	International	35:03	89:59	284	109
Nashville	Metropolitan	36:07	86:41	605	110
TEXAS					
Abilene	Municipal	32:27	99:41	1790	110
Amarillo	Air Terminal	35:14	101:42	3604	111
Austin	Mueller	30:18	97:42	621	111
Brownsville	International	25:55	97:28	20	112
7) Corpus Christi	Cliff Maus	27:46	97:26	44	112
Dallas	Love Field	32:51	96:51	488	113
El Paso	International	31:48	106:24	3916	113
Fort Worth	Greater Southwest	32:50	97:03	576	114
Galveston	Scholes Field	29:16	94:51	9	114
8) Houston	Intercontinental	29:58	95:21	96	115
Houston	International	29:39	95:17	50	115
Larado	Municipal	27:32	99:29	512	116

Location	Airport	Lat. (N)	Long. (W)	Elev. (Ft.)	Page
Longview	Gregg County	32:23	94:43	373	116
Lubbock	Regional	33:39	101:50	3242	117
Midland	Midland-Odessa	31:56	102:12	2858	117
Port Arthur	Jefferson County	29:57	94:01	22	118
San Angelo	Mathis Field	31:22	100:30	1908	118
San Antonio	International	29:32	98:28	794	119
Tyler	Pounds Field	32:21	95:24	551	119
Waco	Municipal	31:37	97:13	508	120
UTAH					
Ogden	Ogden	41:12	112:01	4446	120
Salt Lake City	International	40:46	111:58	4227	121
VERMONT					
Burlington	International	44:28	73:09	340	121
VIRGINIA					
2) Charlottesville	Charlottesville-Albemarle	38:08	78:27	644	122
Lynchburg	Municipal	37:20	79:12	937	122
Norfolk	Norfolk Regional	36:54	76:12	30	123
Pulaski	New River Valley	37:05	80:47	2105	123
Richmond	R. E. Byrd	37:30	77:20	177	124
Roanoke	Municipal	37:19	79:58	1176	124
Washington, DC	Andrews	38:49	76:51	274	125
Washington, DC	Dulles	38:57	77:27	323	125
Washington, DC	National	38:51	77:02	65	126
VIRGIN ISLANDS					
St. Croix	Alex Hamilton	17:42	64:48	55	126
St. Thomas	H. S. Truman	18:20	64:58	15	127
WASHINGTON					
Everett	Paine Field	47:55	122:17	613	127
Moses Lake	Grant	47:11	119:19	1182	128
Olympia	Municipal	46:58	122:53	215	128
Seattle	Boeing Field	47:32	122:18	30	129
Seattle	Seattle-Tacoma	47:27	122:18	450	129
Spokane	International	47:38	117:32	2365	130
Yakima	Air Terminal	46:34	120:32	1066	130
WEST VIRGINIA					
Beckley	Raleigh County	37:47	81:07	2514	131
Charleston	Kanawha	38:22	81:36	951	131
8) Huntington	Tri-State	38:22	82:33	828	132
Parkersburg	Wood County	39:21	81:26	864	132

Location	Airport	Lat. (N)	Long. (W)	Elev. (Ft.)	Page
WISCONSIN					
Green Bay	Austin Straubel	44:29	88:08	702	133
La Crosse	Municipal	43:52	91:15	663	133
Madison	Truax Field	43:08	89:20	866	134
Milwaukee	Mitchell Field	42:57	87:54	693	134
2) Oshkosh	Wittman	44:00	88:34	785	135
WYOMING					
Casper	Air Terminal	42:55	106:28	5290	135
Cheyenne	Municipal	41:09	104:49	6144	136

1) Insufficient digitized weather data from Huntsville-Madison County Airport.

2) Hours 0700-2100 LST only are summarized.

3) Insufficient digitized weather data from International Airport.

4) Insufficient digitized weather data from Thompson Field.

5) Insufficient digitized weather data from International Airport.

6) Insufficient digitized weather data from Greenville-Spartanburg Airport.

7) Insufficient digitized weather data from International Airport.

8) Summary is based on eight 3-hourly observations per day.

MITRE Technical Report

MTR-7224

Some Fail Operational Characteristics of Future Systems with Reduced Spacing

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ABSTRACT

This paper takes a first look at the problem of future ATC systems coping with a surveillance outage in the terminal area. Of concern is the impact of reduced longitudinal separation standards on final approach leading to more airspace congestion, and therefore a more complex situation to deal with when a surveillance failure occurs. The impact of future systems such as automated metering and spacing, DABS/IPC, BCAS, RNAV and MLS is considered. While the results presented in this paper are certainly not a complete answer, they serve to demonstrate the significance of the fail operational problem, and should be of value in current planning efforts and in launching future study efforts.

CONCLUSIONS

1. A reduction in the minimum along-course separation standard on final approach from 3 nmi to 2 nmi will be accompanied by the increase in traffic level on arrival routes. This increase will be of the order of 33%.

2. By automating the metering and spacing process, and thereby allowing the use of a more strict delay criterion for clearing aircraft into the airport, the terminal airspace traffic level is reduced from that of a manual system. However, an automated system using a 2 nmi standard will still result in about a 25% higher terminal airspace traffic level than a manual system using a 3 nmi standard.

3. In the event of a complete surveillance outage at a major airport during a peak traffic period, the ATC system would have to cope with 25% more arrival traffic via its special non-radar fail operational procedures.

4. Over the time period immediately following a catastrophic surveillance failure, the current ATC system has some difficulties in dealing with even today's traffic levels. Thus, the traffic increase due to reduced separation minima could be very difficult to cope with in the event of a surveillance failure.

5. DABS/IPC, BCAS and VOR/DME based RNAV, all possible fail operational aids, do not appear to be significant aids for the ATC system in dealing with the problem posed here.

6. Special MLS based RNAV fail operational procedures, however, have great potential for keeping this fail operational problem at today's level of difficulty, even with a 25% increase in traffic, and possibly can even improve the situation.

7. MLS based time navigation fail operational approach procedures have the potential for completely solving the problem.

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LIST OF ILLUSTRATIONS

1. INTRODUCTION

This paper looks at the subject of reduced longitudinal separation standards on final approach from the fail operational viewpoint. The following are assumed:

1. the use of a minimum two nautical mile standard (as opposed to today's three nautical mile standard) at a major airport, and

2. a surveillance system outage (both primary and secondary radar) at the airport during instrument meteorological conditions.

Then the questions at hand are:

1. What would be the ability of today's ATC system to deal with the aircraft under its control during the immediate period of time after which the failure has occurred, and before backup non-radar approach procedures can be put into stable operation? (Remember, with 2 nmi spacing there will be more arriving aircraft in the terminal airspace than in today's system.)

2. What improved fail operational capabilities would come about from possible future systems such as metering and spacing, DABS/IPC, BCAS, RNAV, RNAV + MLS, RNAV + MLS + time navigation?

3. How do these planned systems compare to each other from the fail operational viewpoint?

In order to make numerical comparisons between possible future systems and today's system, a measure has to be defined. For the purposes of this study, that measure is the number of aircraft on arrival routes which must be controlled via special ATC non-radar procedures after the hypothesized failure has occurred. That is, after a surveillance failure occurs, some arriving aircraft are still permitted to land without any ATC interference, while others are diverted to special holding fixes or elsewhere into the airspace. Those permitted to continue on to land present no special problems to the ATC system. The number of aircraft that are diverted, however, serves as a measure of the difficulty ATC will have in coping with a surveillance outage. Thus, it would appear that this number serves as a reasonable measure of difficulty. In order to understand how sensitive the performance of fail operational procedures is to changes in this number, Section 2 of the paper takes a look at Chicago O'Hare with a 3 nmi minimum separation standard on final approach and with a hypothesized 2 nmi standard, and qualitatively discusses the fail operational problem. The remaining sections then use the "additional number of aircraft" measure as a means for comparison among future systems.

2. DESCRIPTION OF CHICAGO O'HARE FAIL OPERATIONAL CHARACTERISTICS

This section describes the existing fail operational procedures used in the event of a complete surveillance outage at the Chicago O'Hare TRACON under instrument meteorological conditions. The purpose of this material is to help the reader calibrate the impact on the ATC system of additional aircraft in the airspace when a catastrophic failure takes place.

The assumed failure is such that all surveillance (from a controller versus a purely surveillance hardware viewpoint) is unexpectedly lost, with no associated communications failures. Such an outage most likely would occur from an ASR failure, but could occur from massive power failures, ruptured video cables, or perhaps some types of ARTS III failures. An ASR failure at Chicago O'Hare is particularly unlikely, as there are two ASRs on the airport. However, this is not the case at all major airports (see Table 2-1). Table 2-2 summarizes the outages of ASR and ARTS for CY75, both throughout the system, and in the major airports listed in Table 2-1. In general, as noted above, an ARTS outage would lead to loss only of beacon data, and thus would not represent the total outage assumed. An ASR failure, apart from backups, would represent such an outage, except for any advance warning inherent in the particular failure.

To illustrate the impact of the assumed outage, a particular O'Hare configuration is discussed. The IFR configuration chosen has parallel arrivals on runways 27L and 27R with parallel departures on runways 32L and 32R. For simplification, a uniform aircraft population (e.g., B727) is assumed.

It should be noted that conditions at other airports will vary from that of O'Hare in terms of traffic levels and aircraft mix, non-parallel approaches, and the levels of fail operational contingency planning and awareness. Although O'Hare encounters the complexities arising from parallel approaches, it has the advantage of no geographical obstructions in the use of its airspace. The presence of mountainous terrain in some areas will present a different set of problems.

2.1 A General Procedural Description

Figure 2-1 illustrates the general arrival/departure routes for the selected IFR configuration for O'Hare (650 feet MSL). The south arrivals are handed over to the TRACON at 7000 feet MSL or higher. The three routes are merged at 5000 feet MSL and the aircraft on this route intercept the glide slope at the same altitude. The north arrivals are also at 7000 feet MSL or higher

TABLE 2-1

BACKUP RADAR FACILITIES (1)

	RADAR COVERAGE WITHIN TRACON CONTROL FACILITY (3)		RADAR COVERAGE AVAILABLE THROUGH ANOTHER CONTROL FACILITY (4)	
Airport (2)	Number of ASR's on Airport	Approximate Distance to Additional ASR Used by TRACON (NMI)	Approximate Distance to Additional Backup ASR (NMI)	Approximate Distance to Backup ARSR (NMI)
ORD	2	--	24	12
ATL	1	--	--	15
LAX	2	--	16, 16, 17	12
JFK	1	23	25	2
DFW	2	--	22	28
SFO	0	9, 18	--	9
LGA	0	11, 18	18	9
MIA	1	14	--	13
DEN	1	--	--	16
DCA	1	10	26	6
BOS	1	--	--	3
PIT	1	--	--	8
STL	1	--	--	2
DTW	1	--	--	7
PHL	1	--	--	22
MSP	1	--	--	8
EWR	1	23	--	23
CLE	1	--	--	12
IAH	0	10	--	13

NOTES: (1) Backups shown for 30 nmi or less (azimuth beacon system garbling may occur at about 2 nmi spacing). Data is accurate to late 1975.

(2) Top 20 U.S. Air carrier airports, in rank order (except Honolulu).

(3) Dual sites are JFK/EWR, ORD, DFW, JAX, SNA/NZJ, LAX, MIA, OAK/NUQ, SAC/MCC, DCA/ADW.

(4) Non-dual ASR or ARSR control is not effective in the transient stages (10-15 minutes) following a surveillance failure.

TABLE 2-2

SUMMARY OF UNSCHEDULED ASR/ARTS OUTAGES CY 75*

Equipment	Facilities	Number of Facilities	Number of Outages	Hours of Outage	Average Outage Duration	Average Number of Outages per Facility
ASR	(TABLE 2-1 FACILITIES)	20	45	75.7	1.68	2.25
	ALL	157	375	561	1.49	2.39
ARTS	(TABLE 2-1 FACILITIES)	17	532	745.3	1.40	31.29
	ALL	62	1219	2368	1.94	19.66

* Data as reported on FAA Form 6040-3, Facility and Service Outage Report, and processed by AAF-240. Summary is published as Reference 7. In addition to unscheduled outages shown, scheduled outages for all facilities number 1891 (2990 hours) for ASR, and 404 (701 hours) for ARTS.

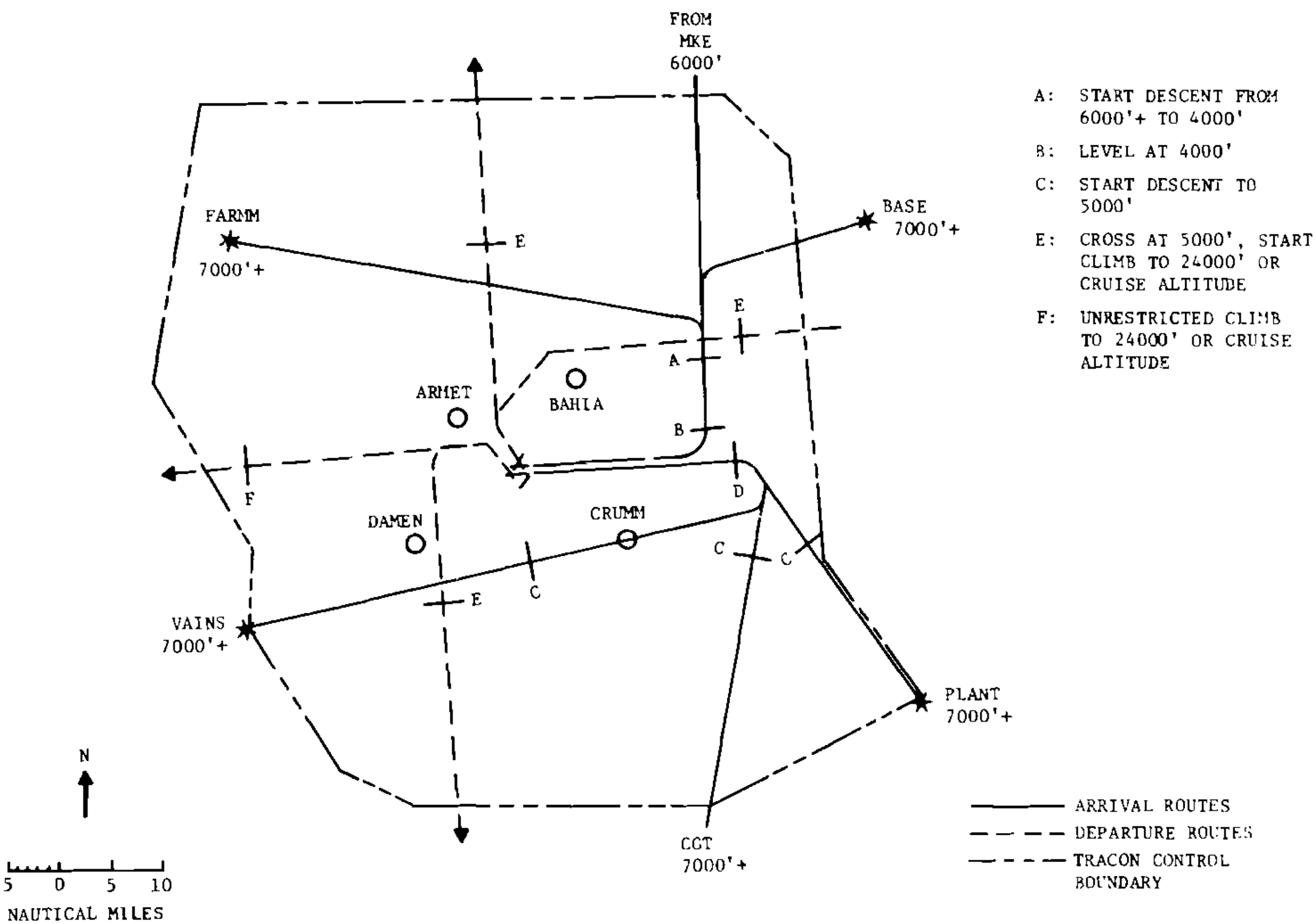

FIGURE 2-1
ARRIVAL DEPARTURE ROUTES FOR O'HARE
(ARR: 27R/L, DEP: 32R/L; IFR CONFIGURATION)

on entering the TRACON control. The aircraft from Milwaukee (MKE) are at 6000 feet MSL. The three north arrival routes merge at about 6000 feet MSL and then descend to and level at 4000 feet MSL before making the final turn to intercept the localizer. The departures climb to 5000 feet MSL after takeoff and after reaching the indicated positions (E on Figure 2-1) climb to 24,000 feet MSL or cruise altitude, whichever is lower. The west departures from runway 32L have a direct unrestricted climb to 24,000 feet MSL or cruise altitude.

Midway airport routes are not shown because they occupy separate airspace sectors and are handled separately. There are four emergency holding areas for O'Hare, shown in Figure 2-1 as ARMET (ORD Radial 314, 8 DME), BAHIA (ORD Radial 035, 10 DME), CRUMM (ORD Radial 125, 12 DME), and DAMEN (ORD Radial 235, 12 DME).

In the event of a surveillance outage, the action required of an aircraft depends on its type (arrival or departure) and location, and is as follows:

1. All arrivals not yet released by the center are held.

2. All departures not yet airborne are held on the ground.

3. Departures are sequentially assigned fixed altitudes of 3000, 4000 and 5000 feet and turned over to the center.

4. One of the parallel arrival approaches is abandoned with the controller addressing the aircraft sequentially to execute missed approaches, join the departure stream at specified altitudes of 3000, 4000, 5000 feet and be turned over to the center for resequencing.

5. Arrivals which are generally committed on the other approach proceed in the normal fashion and land.

6. All other arrivals are sent to one of the four emergency holding patterns shown in Figure 2-1. These are published in the Terminal Airways Charts. The controller assigns altitudes from 6,000 to 10,000 feet (up to 12,000 feet with ARTCC coordination).

The detailed consequences of the general procedures described above depend on the specific number, type and location of all aircraft in the system at the time of the failure, as well as the individual controller's approach to the situation. Some details of the scenario under 3 nmi minimum separation as well as a potential 2 nmi minimum separation are described in the next sections.

2.2 Procedural Details with 3 nmi Minimum Separation

Figure 2-2 shows the aircraft within Chicago O'Hare terminal control. Aircraft have been spaced according to a 3 nmi separation standard, at maximum throughput capacity. Average spacing is greater by a mile on final approach, and by another mile prior to final speed descent.

The use of an additional mile of spacing on final accounts for the real world practice of leaving a buffer in spacing to assure minimums will not be violated in those cases where large performance deviations occur (e.g., speed variation, large pilot response time).

As mentioned in the previous section, the departure controller appropriately assigns altitudes of 3000, 4000 or 5000 feet to the airborne departure aircraft within his control, until the ARTCC takes over.

For arrivals, let us assume that the controllers decide to abandon the ILS approach to the southern runway 27L (due to generally higher altitudes of aircraft on that approach). In such a scenario, the four arrival aircraft on the north runway 27R will land normally. The remaining eight aircraft will be addressed sequentially (i.e., 5, 6, 7, 8, ----, 12) by the controller and assigned altitudes for holding at ARMET and BAHIA between 6,000 and 10,000 feet MSL (12,000 feet if required) at 1,000 feet intervals.

On the south side, the situation is more critical. The first four aircraft will be asked by the arrival controller to execute missed approaches and in coordination with the south departure controller will join the departure stream at sequential altitudes until the ARTCC takes control. The remaining eight aircraft will then be sequentially addressed by the arrival controller in a manner similar to the north complex in creating stacks at CRUMM and DAMEN. However, in the authors' estimations it would seem that an alternate, equally safe and operationally easier procedure would be to permit aircraft stablized on ILS localizer on either runway to proceed. It can be shown that the risk of collision with other approaches on the parallel approach course is vanishingly small.* If this is done, the first five

* This risk (e.g., Reference 5) may be considered significant over many thousands of operations; however, only four operations are involved here, and the risk of merging these aircraft with departures probably exceeds that of making parallel approaches.

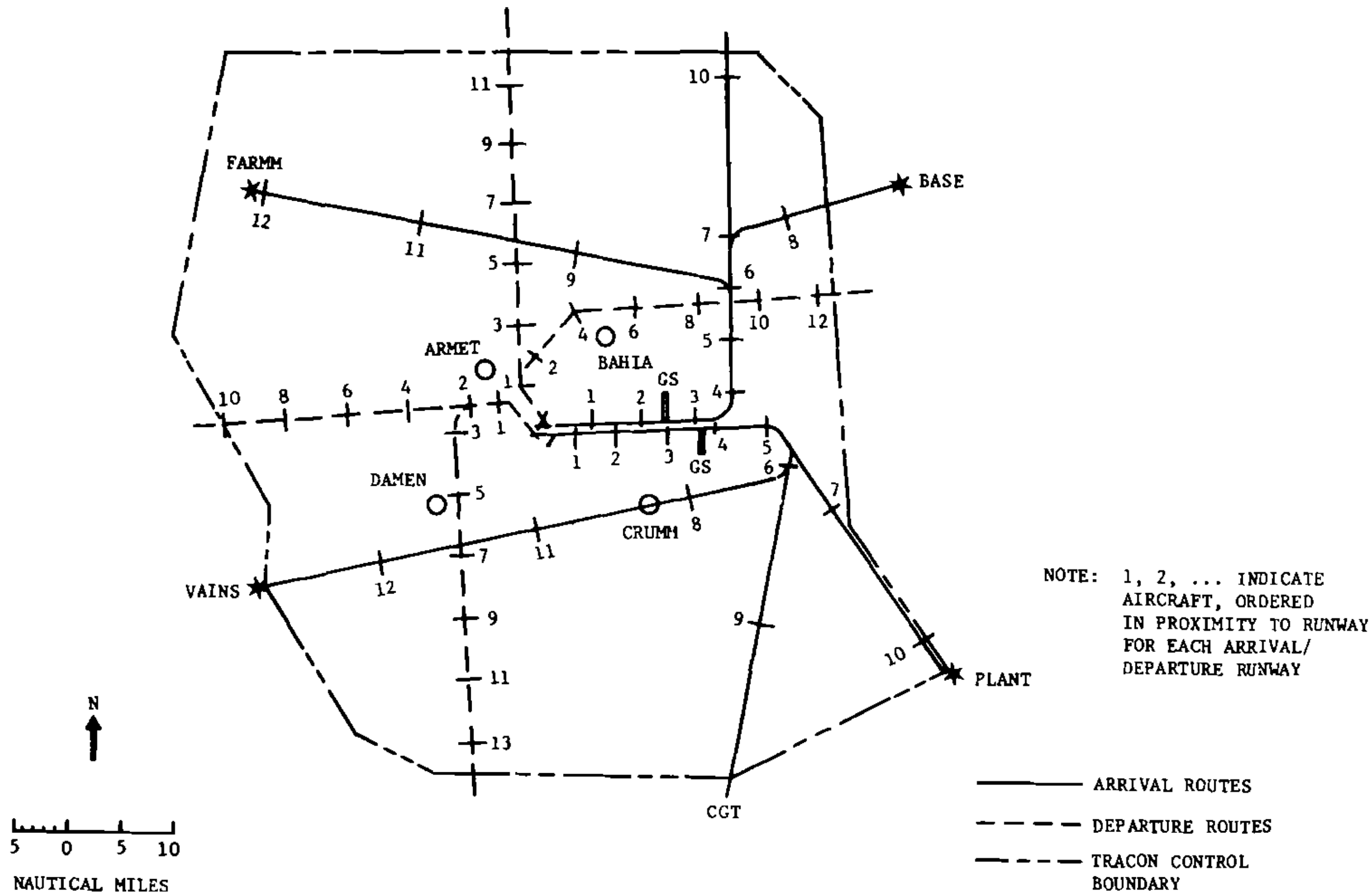

FIGURE 2-2
AIRCRAFT WITHIN THE O'HARE TERMINAL CONTROL
(3 NMI MINIMUM SPACING)

aircraft on 27L need no controller attention. The fourth aircraft on 27R, not having made the final turn, would no longer be permitted to land.

To summarize, the transformation from a radar to a non-radar environment, caused by a surveillance outage under saturation conditions involves the following critical elements:

1. Increased ATC complexity and uncertainty due to special ATC requirements: At O'Hare, the north arrival controller must follow special procedures for eight aircraft (nine under the authors' alternative procedure) while the south controller must, in addition, interact with the departure controller in handling the twelve aircraft (seven under the authors' alternative procedure). In general, eight aircraft are estimated as a very heavy load for the terminal controller under such conditions and twelve is an estimated maximum that he can handle. It should be noted that in high workload periods there will be an additional south and/or north approach controller, relieving the specific workload, but possibly not helping the problem in terms of its complexity due to increased coordination requirements.

2. The capacity of the holding stacks under current assignments, can be up to 6 per stack, or 24 aircraft. The scenario presented here requires 16 aircraft to be held.

3. The merging of the arrival aircraft, executing missed approaches (on the south complex), with the departure stream is another critical area of concern.

2.3 Procedural Details with 2 nmi Minimum Separation

Figure 2-3 shows the impact of a 2 nmi minimum separation. Under this scenario, all arrival aircraft are 1 nmi closer and the number of airborne arrivals in the system has increased from 24 to 31 (as the hourly throughput capacity goes from 128 to 172). Generally this will imply additional approach controllers will be on duty on both south and north approaches. These controllers will handle the aircraft on initial approach segments.

A procedure similar to the previous section results in:

1. Five aircraft in the north complex landing normally (four under authors' alternative procedure).

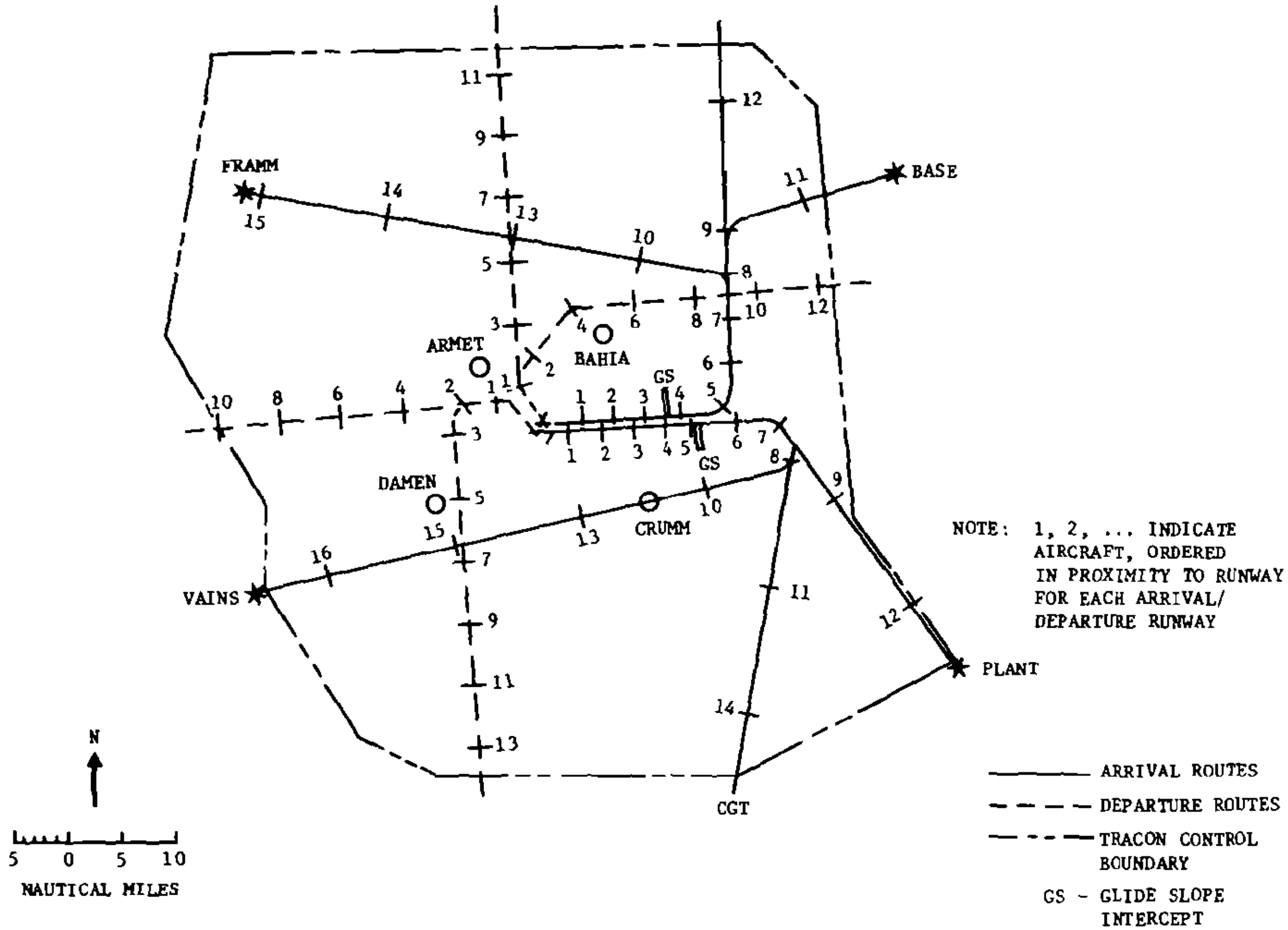

FIGURE 2-3
AIRCRAFT WITHIN THE O'HARE TERMINAL CONTROL
(2 NMI MINIMUM SPACING)

2. Ten aircraft in the north complex requiring special ATC procedures to stack at ARMET and BAHIA (eleven under authors' alternative procedure).

3. Six aircraft in the south complex executing missed approaches and joining the departure stream (alternately, landing in usual fashion if the authors' alternative procedure was deemed adequate).

4. Ten aircraft in the south complex requiring special ATC procedures to stack at CRUMM and DAMEN.

5. The departures are handled as in the previous example, with no additional workload.

Table 2-3 summarizes the traffic situation under both 3 nmi and 2 nmi minimum separations. The implications of a 2 nmi minimum separation under such a scenario are:

1. The North arrival controller is required to handle two additional aircraft while the south arrival controller has four additional aircraft (two under the author's alternative procedure).

2. The capacity for holding aircraft is now utilized at 87.5%, and requires ARTCC coordination.

3. All the operations of special ATC procedures increase in complexity and become more critical due to increased number of aircraft.

Some of these problems may be resolved simply by increasing the size of the hold areas or creating new such areas, but the major problem of ATC uncertainty and complexity, already near saturation, would become even more critical. This is true even if additional controllers are present, as extensive coordination is necessary.

It should be noted that the traffic levels used in the illustrations of this section represent a theoretical saturation condition which may not occur with any regularity in actual operations at O'Hare.

TABLE 2-3

SUMMARY OF HANDLING OF O'HARE ARRIVAL TRAFFIC

	ARRIVAL STREAM	3 NMI O'HARE PROCEDURE	MINIMUM SEPARATION AUTHORS' ALTERNATIVE*	2 NMI O'HARE PROCEDURE	MINIMUM SEPARATION AUTHORS' ALTERNATIVE*
Total in Terminal Airspace	27R	12		15	
	27L	12		16	
Permitted to Continue Approach	27R	4	3	5	4
	27L	0	5	0	6
Handled by Emergency Fail Operational Procedures:					
- Missed Approaches	27R	0	0	0	0
	27L	4	0	5	0
- Additional Holding in Emergency Stacks	27R	8	9	10	11
	27L	8	7	11	10

* Parallel approaches continued for those aircraft stabilized on ILS localizer.

3. FAIL OPERATIONAL IMPACT OF AUTOMATED METERING AND SPACING

With regard to fail operational considerations, the primary differences between automated metering and spacing and today's manual metering and spacing are the rate at which landings can be made and the criterion used to clear an aircraft from the holding fix into the airport. An automated system would increase the landing rate (Reference 1) and this would fend to raise the number of aircraft in the airport airspace at a given time. This would tend to make the fail operational problem more difficult to deal with. However, in an automated system, only when an aircraft requires 4 minutes or less controllability to correct initial and flying errors is it cleared into the airport. In today's manual system, where precise prediction of such controllability requirements is not a task for which a controller is as well suited as a computer, and where pilots prefer not to be held, aircraft with much larger correction time requirements are cleared into the airport and then, via path stretching procedures, the initial and flying errors are corrected. Therefore, the result of automation here is to reduce the number of aircraft simultaneously in the airport airspace and thereby ease the fail operational situation. Thus, to determine the overall impact of automating metering and spacing on fail operational procedures when the surveillance failure occurs requires an in-depth analysis.

A simple approach can be used to quantify the difference in number of aircraft in the airspace between automated and manual metering and spacing systems. The assumptions are: a) in the average case, the manual system clears aircraft requiring upto 8 minutes of controllability into the airport airspace. (This controllability can be accomplished by allowing an elongated downwind leg equal to 4 minutes of delay, back and forth. This is illustrated in Figure 3-1. At a ground speed of 180 knots along this stretched path, this equates to a 12 nautical mile path stretching, certainly not uncommon in today's system.), b) the manual system lands 33 aircraft per hour on a runway or about one aircraft every 109 seconds, and c) it nominally takes an aircraft 15 minutes (900 seconds) of flight time from holding fix to touchdown.

Then, in order to have aircraft lined up to achieve this 33 per hour capacity, there would have to be a minimum of 8 aircraft in the airport airspace (i.e., one every 109 seconds for 900 seconds). Since the manual system permits an additional 8 minutes (480 seconds) to be used up by flying elongated paths in the airport airspace, there would be 4 additional aircraft in the airspace (i.e., another 480/109). The total effect is 12 aircraft in the airspace per arrival runway.

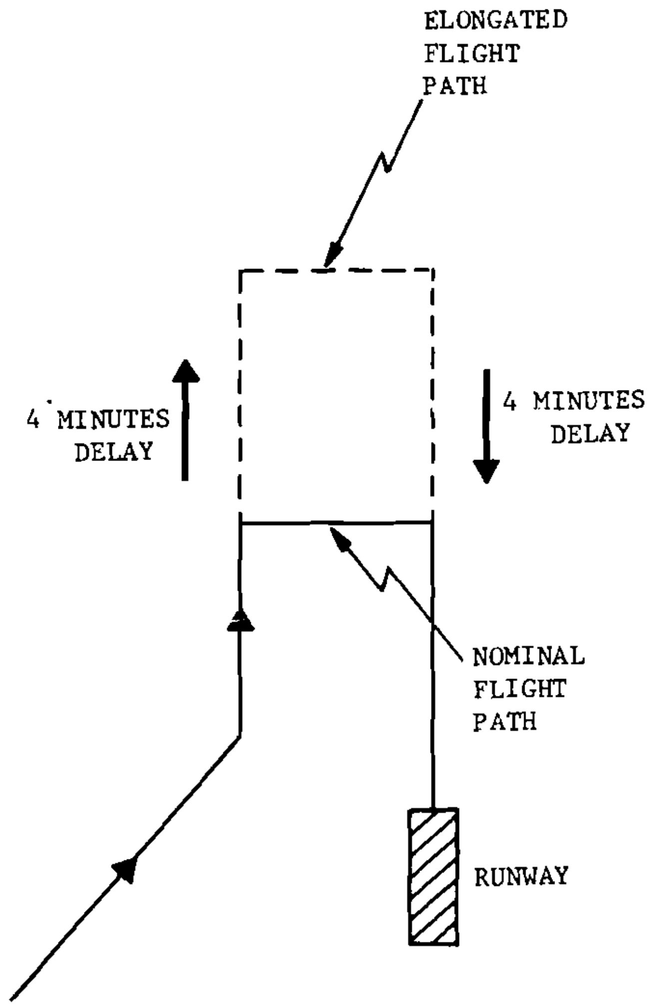

FIGURE 3-1
COMMONLY USED PATH CONTROL
GEOMETRY FOR SPACING AIRCRAFT

By comparison, an automated metering and spacing system would land, say 36 aircraft per hour or one aircraft every 100 seconds. Now the 15 minute flight time results in a minimum 9 aircraft in the airspace. Using the 4 minute (240 seconds) holding criterion, an additional 2 aircraft (i.e., 240/100) requiring 4 minutes or less controllability to correct initial and flying errors would be cleared into the airport. This results in a total of 11 aircraft. Thus, even though automated metering and spacing yields a higher landing capacity then a manual system (assumed here to be 36 per hour versus 33 per hour), the airspace traffic level is actually reduced from 12 with a manual system to 11 aircraft with an automated system, per arrival runway.

The additional impact of a reduced separation standard on final approach would be to increase the number of aircraft in the airport airspace when the surveillance failure occurs. For a 2 nmi standard the effect would be to increase the simultaneous aircraft count to 16 with a manual system (assuming a capacity of 42 aircraft per hour or an 85 second interval between successive arrivals), while for the automated system the count would be 15 aircraft (assuming a capacity of 48 aircraft per hour or an 75 second interval between successive arrivals). Table 3-1 summarizes the results.

From Table 3-1 the following conclusions may be drawn:

1. A reduction in the minimum along-course separation standard on final approach from 3 nmi to 2 nmi will be accompanied by an increase in traffic level on arrival routes. This increase will be of the order of 33%.

2. By automating the metering and spacing process, and thereby allowing the use of a more strict controllability criterion for clearing aircraft into the airport, the terminal airspace traffic level can be reduced from that of a manual system. However, an automated system using a 2 nmi standard will still result in about a 25% higher terminal airspace traffic level than a manual system using a 3 nmi standard.

3. Thus, going from today's system to automated metering and spacing with reduced separation standards represents an increase in the difficulty of coping with a surveillance outage. That is, the ATC system must carry out its fail operational procedures on about 25% more arrival traffic (i.e., 15 aircraft per arrival runway as opposed to 12 aircraft per arrival runway).

TABLE 3-1

SUMMARY OF IMPACT OF REDUCED SEPARATION
WITH AUTOMATED METERING AND SPACING

(a) Aircraft Per Arrival Runway Simultaneously in Terminal Airspace

	3 nmi Sep Standard	2 nmi Sep Standard
Manual M&S	12	16
Automated M&S	11	15

(b) Single Runway Landing Capacity

	3 nmi Sep Standard	2 nmi Sep Standard
Manual M&S	33	42
Automated M&S	36	48

4. Based on the discussion presented in Section 2 with regard to the difficulties in carrying out fail operational procedures, it would be useful to have some added capability in this area if the minimum separation standard is, in fact, reduced.

4. EVALUATION OF SOME POSSIBLE FUTURE SYSTEMS

The FAA is currently developing several new systems which have potential fail operational benefits. These include: DABS/IPC, BCAS and MLS. Furthermore, area navigation (RNAV) and time navigation (TNAV) are already existing navigation system capabilities which potentially provide fail operational benefits that could conceivably be put into widespread operation in the future. This section discusses each of these systems and their ability to back up the hypothesized surveillance outage discussed earlier. The discussion is oriented to the traffic resulting from the assumption of the two nautical mile longitudinal separation standard on final approach in an automated metering and spacing environment. The question of concern is whether or not any of these improvements will aid the ATC system in dealing with the 25% increase in arrival traffic which must be handled via fail operational procedures in the event of surveillance outage.

4.1 DABS/IPC

In this futuristic scenario, DABS (and not ATCRBS) would be the surveillance system hypothesized to fail. Thus, the DABS/IPC system located at the airport in question would in general provide no backup capability, having itself failed. If, however, it has been the ARTS III which initiated the failure, DABS/IPC would provide some backup capability. In fact, the DABS/IPC system is really geared to backing up controller errors, pilot errors, ATC computer system failures (e.g., ARTS III failure) and radio communications failures. (In the case of a radio communication failure, the data link in DABS is a communications source which provides a redundant communications channel to radio communications.) Within the DABS/IPC concept there is the possibility of redundant IPC coverage provided by a nearby DABS/IPC site. This nearby site would be utilized to detect automatically and resolve potential collisions at the airport in question, in those cases when the airport's own surveillance site has failed. However, to be completely successful at providing this redundant IPC service, the backup site must be close enough to the airport at which the failure has occurred so as to have a line of sight down to altitudes reasonably close to the ground. This requirement is illustrated by the fact that in the example traffic situation of Section 2 where a 2 nmi separation standard is assumed, 10 aircraft are below 4000 feet at the time of failure. To achieve this line of sight requires redundant DABS/IPC sites within 20 to 30 miles of each other. The expense of such redundancy for major airports as a general rule may be prohibitive. However, the validity of this point should be substantiated in future work efforts. An important point worth noting in discussing this DABS/IPC concept as a fail operational aid, however, is that while it can protect against a mid-air collision, it gives no help to the controller in sorting out his traffic. Thus, the problems described in Section 2 are not really resolved; only the worst potential outcome is avoided.

4.2 BCAS

A possible fail operational capability to the hypothesized surveillance outage is provided by BCAS. Within the BCAS concept there are two possible modes of operation: active and passive. The passive mode requires aircraft to listen in to aircraft ATCRBS responses to a minimum of two ground sites. Since, in the general hypothesized situation, the airport ATCRBS site has failed and is therefore not soliciting responses, aircraft using passive BCAS would have to be within coverage of two remote sites. As previously discussed in the DABS/IPC material, this level of coverage at the lower altitudes is probably not going to be available as a general rule. Since, as also presented in the DABS/IPC discussion, the lower altitudes are where a good portion of the backup capability is needed, the passive BCAS mode is probably not a complete answer. In the event the failure is due to ARTS III, passive BCAS will provide some backup capability.

The active BCAS mode, however, does provide a solution which is independent of ground sites. Unfortunately, the ability of the active BCAS mode to perform adequately in the high density environment where spacings of 2 nmi are utilized is questionable, although not to be ruled out as a possibility. Thus, before the BCAS can be considered as an answer to this problem, the active BCAS performance related to synchronous garble in a high density airport must be demonstrated as adequate. Furthermore, as noted in the DABS/IPC discussion, the ability to back up the controller by providing protection against a mid-air collision is not a complete solution, since it does not help the controller to sort out his traffic via the fail operational procedures available to him.

4.3 VOR/DME Based RNAV

Two dimensional area navigation (2D-RNAV) utilizing VOR/DME provides the ATC system with a potential mechanism for improved fail operational capability. With 2D-RNAV, aircraft can be routed on STARS (Standard Terminal Arrival Routes) to the airport and with the ATC system utilizing special RNAV path adjustment procedures to achieve spacing, the pilot can continue to navigate throughout the spacing process. Appendix A presents a description of this RNAV procedure. The RNAV procedure differs from today's radar vector procedures where the aircraft is usually navigated to the final approach course via radar vectors supplied by ATC.

In the case of the hypothesized surveillance failure, the value of having the pilot continuously navigating is that when the failure occurs the pilot knows exactly where he is and can continue to navigate the STAR and make his approach. Of course, when utilizing this failure mode the concern in high traffic situations is the possible overtake of one aircraft by another.

The RNAV procedure which provides this fail operational capability is analyzed in Reference 2. In that report it is shown that under normal conditions the RNAV procedure is as flexible as radar vector procedures and requires less controller-to-pilot communications. Subsequent NAFEC real-time simulations have verified this conclusion. Of concern here, however, is the question of how much fail operational capability RNAV offers. One possible way to measure this is to assume the traffic model of Figure 4-1 as the hypothetical situation of concern just when the surveillance failure occurs, and determine what happens from this point on in time. It is assumed that the fail operational procedure from that point in time is for each aircraft in the system to navigate the standard route using a specified speed profile and continue on to land. Due to aircraft navigation and speed variations the possibility exists for aircraft to get considerably closer than would be desirable. Therefore, as in today's system, the number of aircraft permitted to continue on their approach must be limited. A measure of the fail operational capability would be the number of aircraft that can continue on to land before the probability of a pair of aircraft getting too close exceeds some amount. If the number of aircraft permitted to land is increased relative to today's system and the increase offsets the previously defined 25% traffic increase due to reduced separations, then the fail operational procedures for aircraft not permitted to continue on to land in this scenario, are no more difficult to execute than in today's system. Using probability distribution assumptions presented in Appendix B for such random variables as location of aircraft at the time of failure, VOR/DME errors, winds, aircraft speed variations, etc., an analysis was performed from which the curve in Figure 4-2 was derived. The analysis method and details are presented in Appendix B and are similar to the analysis method in Reference 3. This curve tells us what the RNAV fail operational approach gives us in terms of an ability for sequential pairs of aircraft continuing on their procedural approaches to maintain separation.

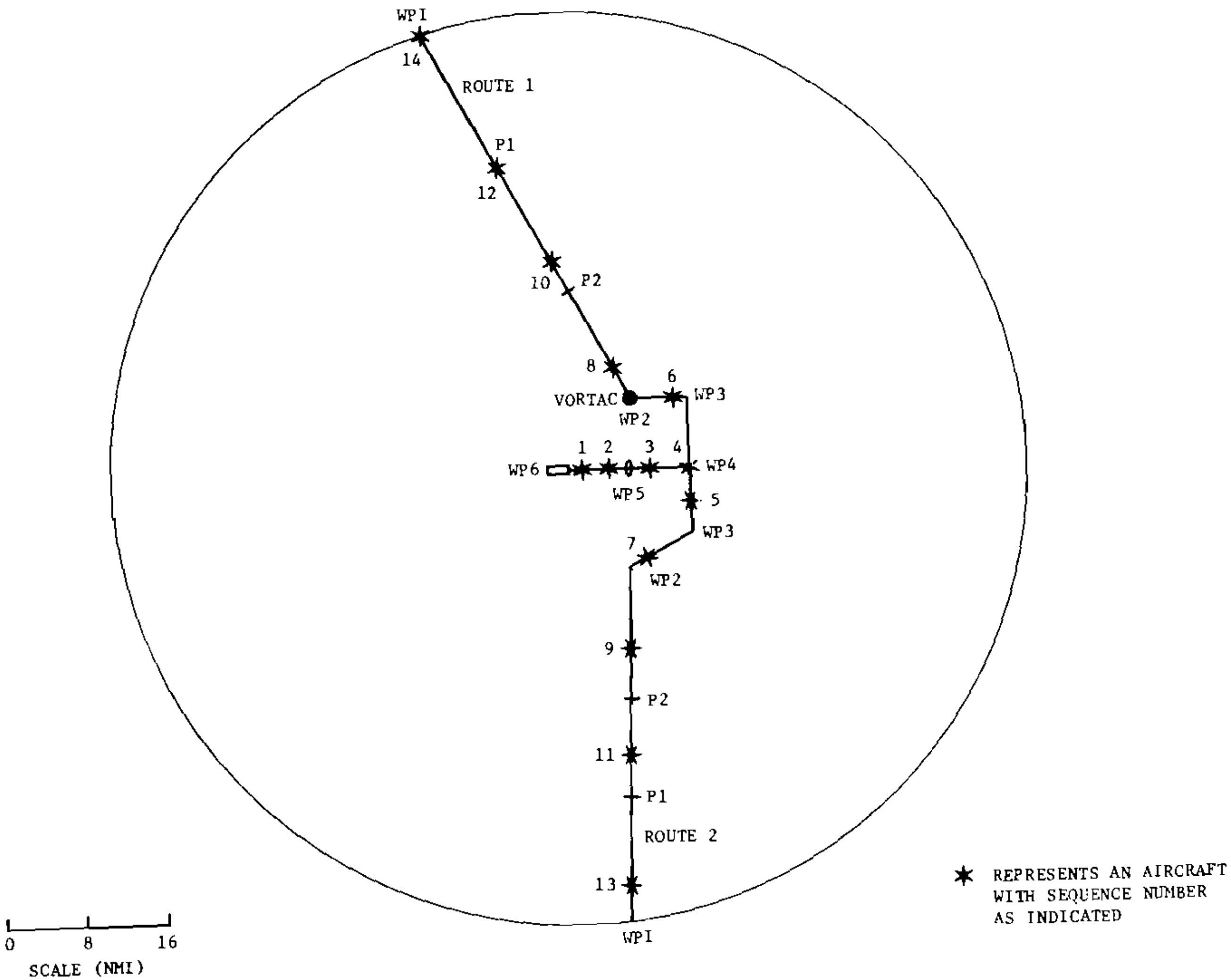

FIGURE 4-1
LOCATIONS OF AIRCRAFT

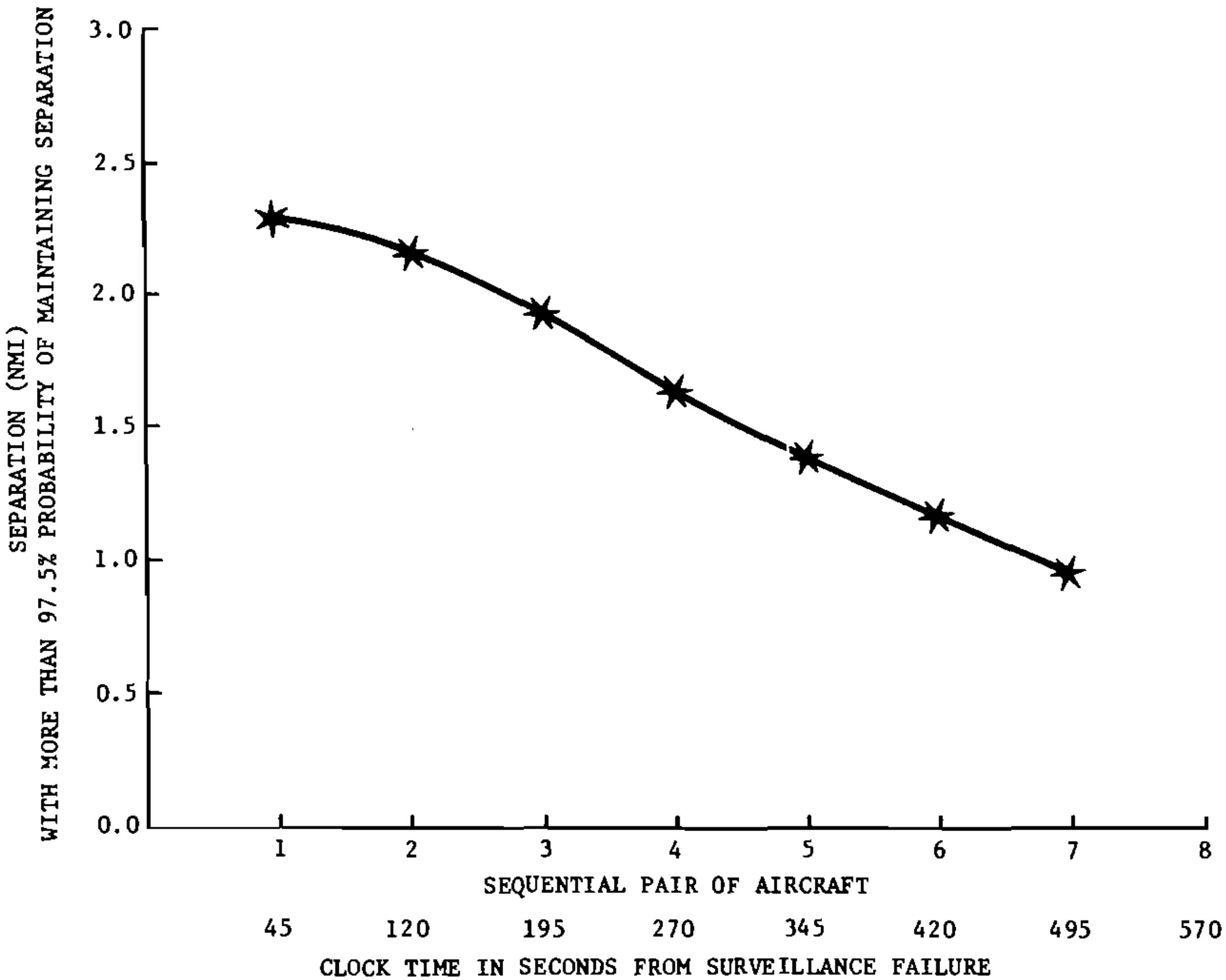

FIGURE 4-2
SEPARATION BETWEEN SEQUENTIAL PAIRS OF AIRCRAFT
WITH A SYSTEM USING 2D-RNAV, VOR/DME

That is, the abscissa of the curve is which pair of aircraft we are talking about (first pair consists of aircraft 1 and 2 in Figure 4-1, second pair consists of aircraft 2 and 3 in Figure 4-1, etc.), and the ordinate is the separation we wish to maintain with 97.5% probability.

A key assumption used here is that in normal performance the automated metering and spacing system will on the average space aircraft by 2.84 nmi, even though a 2 nmi minimum spacing is permissible. This added spacing is utilized for the purpose of assuring that under normal conditions (i.e., surveillance working) minimum separations won't be violated with more than a one in a thousand probability. Thus, when the surveillance failure occurs, as seen from Figure 4-2, about 3 pairs (or 4 aircraft) can continue on to land with a 97.5% probability of maintaining the 2 nmi minimum on a pair by pair basis. Furthermore, an additional aircraft can land with 97.5% chance of maintaining 1.5 nmi spacing. As discussed in Appendix B, a key factor in determining these values is the inaccuracy of the VOR/DME RNAV capability. For example, a 1/2 nmi navigation error by an aircraft in terms of the location of its base leg relative to the runway results in a 1/2 nmi along-course spacing error when that aircraft turns on to final. From Figure 4-1 it is seen that the case of 4 aircraft continuing on to land includes only those aircraft already on final approach. Since the current procedures described in Section 2 already permit these aircraft to land, no ATC fail operational benefit is gained from RNAV. For the 1.5 nmi criterion a gain of one additional aircraft going on to land is achieved.

In view of the fact that with the 2 nmi separation criterion there will be 3 additional aircraft in the airspace relative to today's system with 3 nmi spacing (see Table 3-1), only one third of the added workload is taken care of, with the added risk of a 1.5 nmi separation, or less, resulting.

In summary, 2 dimensional RNAV based on VOR/DME signals does not seem to be a good answer to the ATC fail operational problem. This is due to the fact that even though RNAV equipped aircraft not yet on final approach are capable of navigating a curved path to intercept the approach coarse, the accuracy of this navigation capability is insufficient to assure that an overtake between successive aircraft won't occur.

4.4 MLS Based Two Dimensional RNAV

Two dimensional RNAV driven by MLS provides the same fail operational procedure described for 2D-RNAV with VOR/DME, but is much more capable due to the high accuracy of the MLS signal. Figure 4-3 presents the traffic scenario of Figure 4-1 with superimposed MLS signal coverage for wide coverage MLS. Figure 4-4 presents the fail operational performance capability of 2D-RNAV with this MLS coverage. This curve has the same abscissa and ordinate as that previously presented in Figure 4-2. Here, however, we see that the use of MLS allows 6 pairs of aircraft to land (i.e., 7 aircraft) with a 97.5% probability for providing at least 2 nmi spacing on a pair by pair basis. From Figure 4-3 we see that the sixth aircraft is on the downwind leg as is the seventh aircraft. Both of these aircraft are under MLS coverage at this point and thus are capable of very accurate navigation. In fact, the major problem in maintaining spacing is speed variation as opposed to navigation errors (this was not the case with VOR/DME based RNAV).

The benefit of an MLS based RNAV fail operational capability is significant. From Table 3-1 we see that the 2 nmi standard requires the handling of 3 more aircraft per arrival runway than today's system would have to cope with. However, MLS permits 3 more aircraft to go on to land than today's system would, with 97.5% chance of maintaining 2 nmi spacing. Thus, this difference provides the potential for an important offloading to ATC, to keep the fail operational problem constant relative to today's system.

Returning to the discussion of Chicago O'Hare presented in Section 2, the reader will recall that the North arrival route is treated in a fashion similar to the approach presented and analyzed here. Thus, this analysis would tend to be applicable to that route. However, the South route at O'Hare is treated in an entirely different way. That is, on the South route all arrivals are diverted so as to avoid the possibility of aircraft on parallel approach courses getting into danger. The reader will also recall that in Section 2 the authors suggested the possible alternate fail operational procedure of allowing aircraft stabilized on the south approach course to continue on to land. This was due to the fact that, based on FAA data on ILS performance, the possibility of aircraft already stabilized on close spaced parallel approach courses getting into danger is remote. In the Chicago O'Hare scenario, with MLS an 2 nmi spacing, at least 6 or 7 aircraft on the South routes would be stabilized on the MLS signal at the time of the surveillance outage. These 6 or 7 aircraft could conceivably continue on to land without danger of interfering with aircraft on the North routes. This leaves the controller with 9 aircraft to handle as opposed to today's 12 aircraft case. Furthermore,

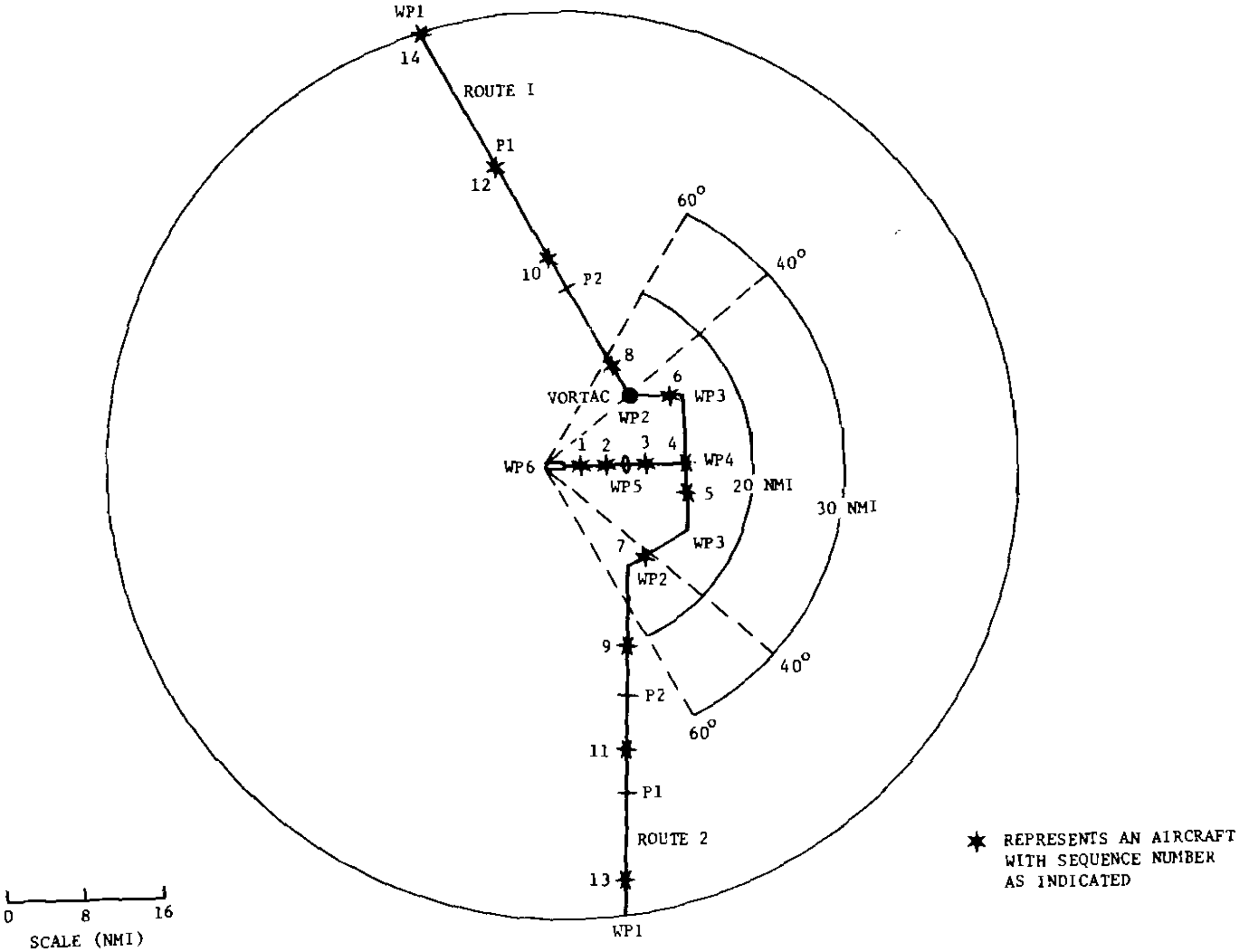

FIGURE 4-3
LOCATIONS OF AIRCRAFT WITH MLS COVERAGE

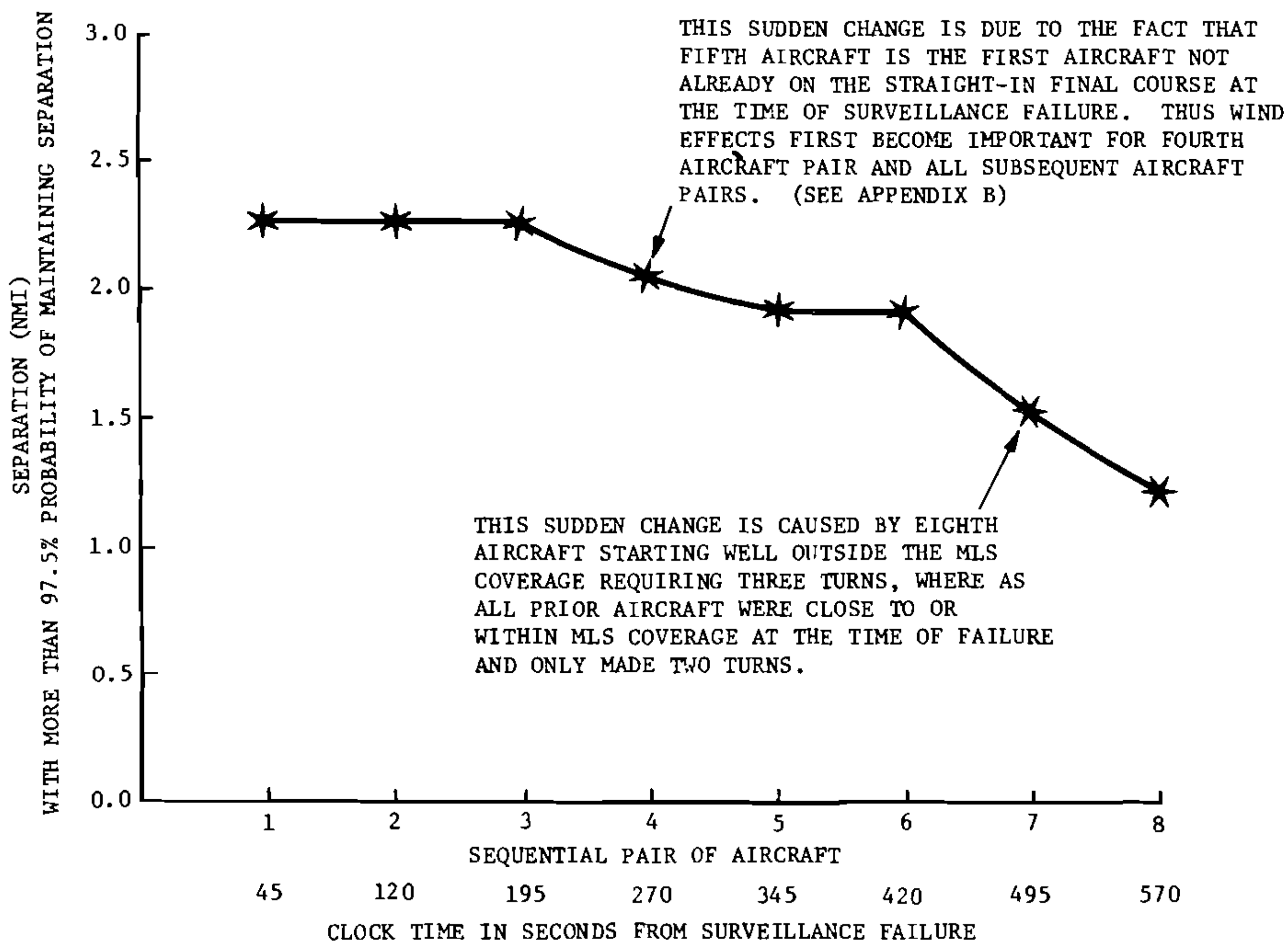

FIGURE 4-4
SEPARATION BETWEEN SEQUENTIAL PAIRS OF AIRCRAFT
WITH A SYSTEM USING 2D-RNAV, ±40° MLS

as was presented in the analysis above, there would be little chance for an overtake situation to occur between successive aircraft on the South route. Thus, the total result of the MLS based RNAV fail operational procedures would be to relieve both the North and South arrival controllers of significant workload. In the case of the North controller his load could be kept about the same as it would be today with a surveillance outage. For the South the improvement would be even more important, since, for the example presented, these routes provided a situation which would be difficult to cope with in an outage situation today, and the improvement would reduce the fail operational workload of the South controller(s) from an estimated 12 aircraft in today's system to 9 aircraft in the future system with 2 nmi spacing, MLS and RNAV.

Table 4-1 summarizes the fail operational handling of aircraft equipped with 2D-RNAV and using VOR/DME and MLS as the navaids.

4.5 MLS Based Time Navigation

A more advanced fail operational concept than those already described would involve the utilization of time navigaiton. These fail operational procedures would work as follows:

> The automated metering and spacing system would have as one of its normal functions the job of deriving a time for each arrival aircraft to be at specified merge points. These times would be transmitted to the pilot (probably requiring data link, possibly achievable with voice). In the event of a surveillance failure each aircraft continues on to its destination without ATC assistance, with separation assured by the originally derived schedule and each aircraft's ability to meet its assignment.

Reference 4 analyzes the ability of such a system to work. The conclusion of that report is that an aircraft equipped with MLS, RNAV and time navigation capability would be able to meet its schedules with great precision (5 second accuracy), so that the ability of such a system to be the primary means for separation assurance in the event of a surveillance outage would be excellent. The benefit of this apprcach is that the ATC system can essentially be relieved of the difficult job of maintaining separation during the immediate period of time following a catastrophic failure. Thus, this approach is the most complete of all possible answers to the fail operational problem.

TABLE 4-1

SUMMARY OF TRAFFIC HANDLING UNDER FAIL OPERATIONAL SCENARIO
(SINGLE ARRIVAL RUNWAY)

	3 NMI MINIMUM SEPARATION STANDARD	2 NMI MINIMUM SEPARATION STANDARD		
SYSTEM	AIRCRAFT ON ARRIVAL	AIRCRAFT ON ARRIVAL	AIRCRAFT PERMITTED TO CONTINUE APPROACH**	AIRCRAFT HANDLED BY EMERGENCY ATC PROCEDURES***
MANUAL M&S	12*	16	4	12
AUTOMATED M&S	11	15	4	11
- VOR/DME BASED RNAV		15	4 (5)	11 (10)
- MLS BASED 2D RNAV		15	7 (8)	8 (7)

* 4 are permitted to continue approach, and 8 need ATC handling (Section 2).

** With probability of at least .975 that aircraft will maintain 2 nmi spacing (numbers in parentheses represent case of 1.5 nmi spacing).

*** Measure of complexity of fail operational scenario.

5. CONCLUSIONS

The results presented in this paper show several important factors in the analysis of ATC fail operational capability. They are summarized in the following paragraphs.

A reduction in the minimum along-course separation standard on final approach from 3 nmi to 2 nmi will be accompanied by an increase in traffic levels on arrival routes within the terminal airspace. This increase will be of the order of 33%.

With an automated metering and spacing system, the criterion for clearing aircraft into the terminal airspace becomes more refined. This results in a slight reduction in the number of aircraft within the terminal airspace, as compared with the current manual system. This somewhat offsets the increase in traffic level due to the reduction of minimum standard on final approach from 3 nmi to 2 nmi. The net result for an automated metering and spacing system using a 2 nmi rule (compared to current manual system and 3 nmi rule) is an increase in traffic level of 25%.

In the event of a complete surveillance outage at a major airport during a peak traffic period, the number of aircraft which would have to be handled by emergency fail operational non-radar ATC procedures would increase by 25%.

Over the time period immediately following a catastrophic surveillance failure, the current ATC system has some difficulties in dealing with even today's traffic levels. Thus, the traffic increase due to reduced separation minima could be very difficult to deal with in the event of such a surveillance failure.

DABS/IPC, BCAS and VOR/DME based RNAV, all possible future fail operational aids, do not appear to be significant aids for the ATC system in dealing with the particular fail operational problem posed here.

Special fail operational procedures using MLS based 2D-RNAV, however, have great potential for keeping this fail operational problem at today's level of difficulty, even with the estimated 25% increase in traffic level, and possibly can even improve the situation.

Fail operational approach procedures using MLS based time navigation have the potential for completely solving the problem, aircraft have the ability to follow an accurate route/time profile without the aid of the ground ATC system.

APPENDIX A

AUTOMATED METERING AND SPACING PROCEDURES WITH AREA NAVIGATION

An RNAV equipped aircraft is capable of navigating by itself along a flight path connecting certain waypoints which are prestored in an onboard computer. If the flight path includes a turn at a waypoint and the onboard system has prior knowledge of this turn (procedural turns), an RNAV aircraft equipped with a turn anticipation capability would automatically initiate the turn before reaching the point. This results in a smooth transition onto a radial to the next waypoint. At some point along the path if the ATC system desires to change the course of the aircraft in order to achieve accurate final spacing, a direct engage command is issued which means that instead of continuing towards the current specified waypoint, the aircraft now flies directly to the next prespecified waypoint. The aircraft under this RNAV metering and spacing procedure would make a turn onto a course that leads to the desired waypoint. The ground system's computer algorithm to compute when to issue a direct engage command is identical to that used for deciding when to issue non-RNAV aircraft the necessary heading for achieving accurate final spacing.

In order to utilize the direct engage concept for area navigation equipped aircraft, a general form of the base leg geometry is shown in Figure A-1. Waypoints WP_1, WP_2, WP_3 and WPG and a 2 dimensional route connecting them are preprogrammed and stored in the onboard computer. Normally an aircraft would turn automatically to waypoint WP_2 when it reaches an appropriate distance from waypoint WP_1 (this distance is the turn anticipation distance which results in a smooth transition onto the radial to WP_2). The ATC system computes a schedule based on a nominal path ABCG and issues a direct engage command to WP_3 when the DICE (direct course error) to WP_3 reaches zero (turn 1). This direct engage command tells the aircraft to turn now direct to WP_3 and navigate to WP_3. In case there is no traffic in front of the aircraft or the aircraft arrives at WP_1 too late, a direct engage command to WP_3 is issued at WP_1. The command is generated early enough to preclude the standard (published) turn to waypoint WP_2. The pilot simply inserts the desired waypoint WP_3 and the aircraft turns onto a path straight to the waypoint. After the aircraft crosses a control arc, a direct engage command to waypoint WPG (Gate) is generated when the DICE to gate goes to zero (turn 2). The shortest path is defined when an aircraft gets a direct engage command to the point WP_3 at WP_1 and another direct engage command to the gate as soon as it reaches the arc (the path is shown by heavy broken lines in Figure A-1). Hence, using the direct engage procedures throughout the base leg region an RNAV

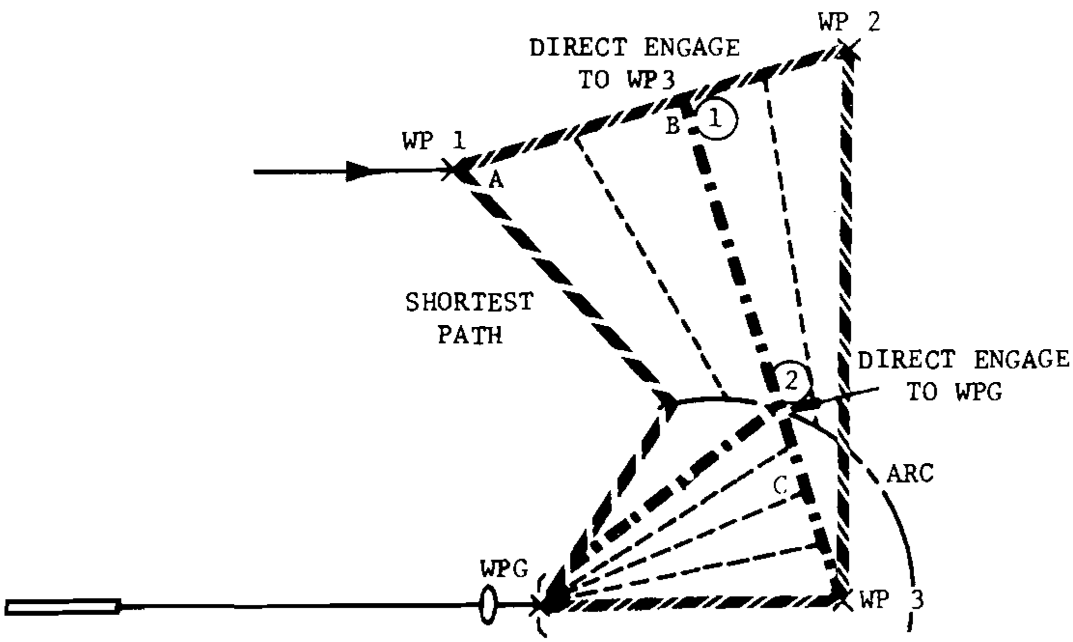

FIGURE A-1

RNAV DIRECT ENGAGE PROCEDURES

aircraft would require two less turn commands and would make one less turn than a non-RNAV aircraft, but would arrive with an additional error at the gate. (Reference 2) In case the ATC system issues no commands (ground system failure or a communication failure) the aircraft has the capability to navigate by itself along the pre-programmed course from WP_2 to WP_3 and finally to waypoint WPG along the path shown in the figure.

APPENDIX B

AIRCRAFT PERFORMANCE AFTER SURVEILLANCE FAILURE

B.1 Airport Capacity and Landing Interval Computations

In an automated metering and spacing environment, under IFR conditions with reduced separation standards, aircraft (not including heavy aircraft) would be required to maintain a minimum separation of 2 nmi on the final approach course. If the aircraft fly an average ground speed of 140 knots on final, in order to maintain a minimum separation of 2 nmi, they would require a time separation of 52 seconds. It has been shown in previous work (Reference 1), that each aircraft could be delivered to the outer marker with a three standard deviations time vatiation of ± 15 seconds, resulting in corresponding three standard deviations interarrival time variations of ± 22 seconds. Hence, besides the minimum time separation required, an additional buffer of 22 seconds should be taken into the consideration by the metering and spacing system for spacing aircraft to account for system variations (response times, speed variations, etc.). This yields a total time separation requirement of about 75 seconds (52 + 22) which corresponds to a maximum capacity of 48 aircraft per hour with a less than 0.1% probability of violating the 2 nmi separation minimum.

B.2 Air Traffic Scenario and Status of Aircraft at the Time of Surveillance Failure

In the event of a surveillance outage, the RNAV equipped aircraft have the capability to navigate all the way to the runway using nominal speeds specified by ATC on various legs of their route (i.e., downwind, baseleg). An analysis is presented in this appendix which shows the performance of RNAV aircraft (in terms of their ability to maintain a certain minimum separation while flying on their own) using a VOR/DME system or an MLS as the navaid. A hypothetical metering and spacing control geometry (using two arrival routes where the performance is sensitive to the navaid accuracy), similar to that designed earlier for possible use at Denver (References 1 and 3), has been selected for the analysis in this paper, and is shown in Figure B-1. The figure represents a 45 nmi terminal area (as recommended by the RNAV Task Force) with speed constraints and altitudes at various control points as indicated. The figure also shows the MLS coverage with the MLS (DME and the azimuth) antennas assumed to be located at the end of a 15,000 foot runway.

Based on the arrival capacity and landing interval discussed in the previous section, and equal distribution of traffic on each of the two routes, a traffic situation has been generated and shown in

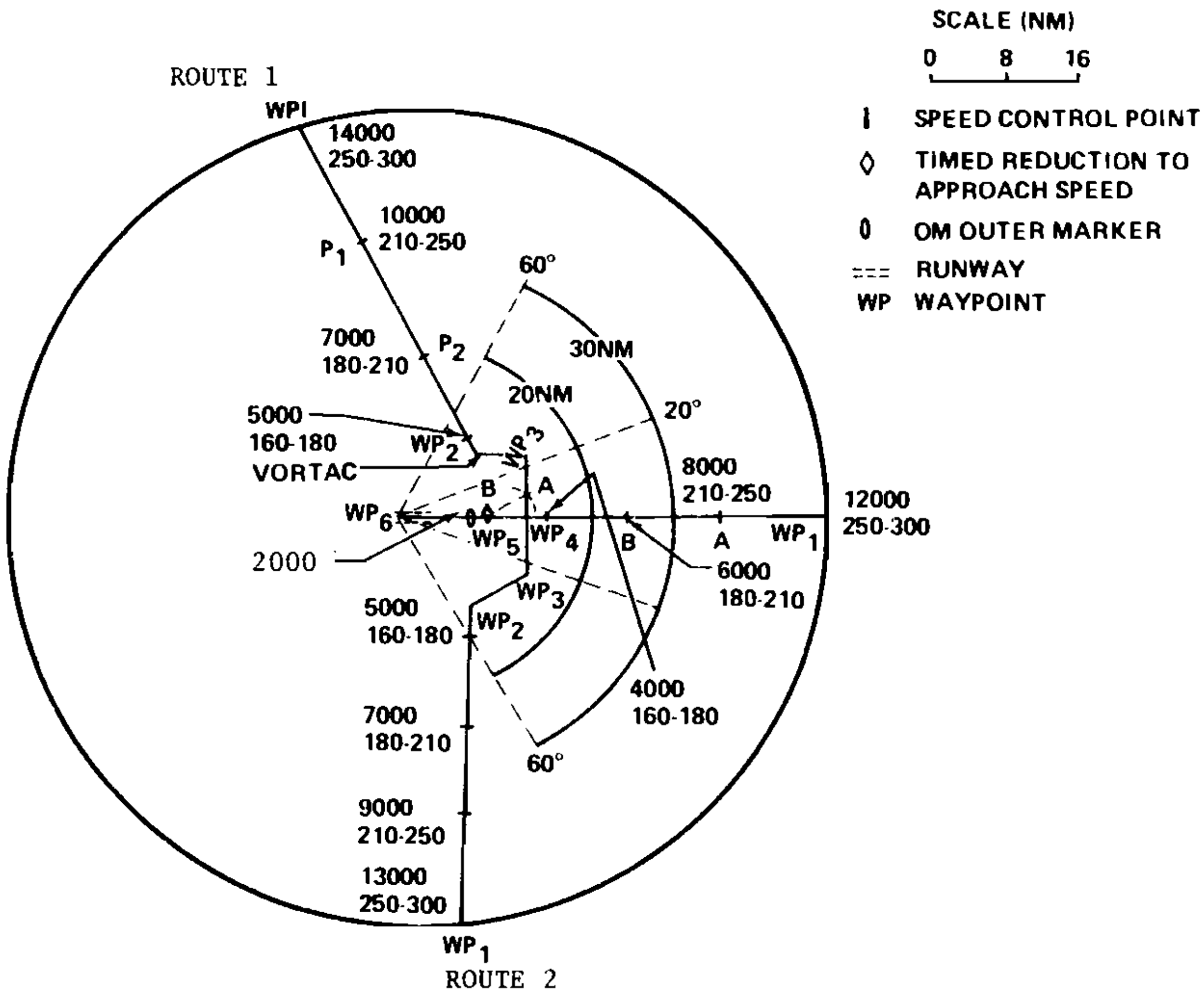

FIGURE B-1

SPEED CONTROL GEOMETRY

Figure 4-3. The traffic scenario assumes that all aircraft were performing nominally and the last aircraft which just entered the system arrived on route 1 at the time when the surveillance failed (i.e., all aircraft in the system were scheduled to land 75 seconds apart). Using nominal speed and altitude profiles for route 1 and 2, the status of all aircraft in terms of their positions, speeds and altitudes, at the time of radar failure, is shown in Table B-1.

B.3 Computation of Minimum Separation Between Sequential Pairs of Aircraft

With the failure of radar surveillance the ATC system loses its monitoring and correction capability with regard to variations in aircraft performance. Under such circumstances aircraft equipped with 2D-RNAV, though capable of navigating all the way to the runway, would have to fly unmonitored and uncorrected, thereby accumulating larger than normal deviations relative to the situation with surveillance working. This means that those aircraft which have to fly larger distances before landing would accumulate larger deviations in landing time due to flight variations, resulting in an increased interarrival time variation, and hence, possibly reduced separation. Thus, the separation between any successive pair of aircraft would continue to have larger probability of a decrease as more aircraft land.

In order to evaluate the separation between any two consecutive aircraft, the deviations accumulated by each aircraft, from the time the surveillance failed until the time the leading aircraft landed, were computed using the error analysis presented in earlier work. (Reference 3) Due to the fact that this analysis is rather elaborate and involved, a detailed description of the analysis is not repeated in this paper. However, a general description of what computations were made is presented. The following system parameters and two standard deviation values of various error components were assumed in the analysis:

1. All aircraft in the system were assumed to be high performance and enter the system with an initial transition speed of 300 knots. After the surveillance outage, the aircraft were assumed to follow procedural altitude and ATC generated speed profiles, making coordinated turns. The aircraft were assumed to decelerate at a nominal rate of 50 knots/min and maintain a descent gradient of 3°.

2. ± 2% error in flying indicated airspeeds due to pilotage and instrumentation.

TABLE B-1

STATUS OF ARRIVAL AIRCRAFT IN TERMINAL AREA

AIRCRAFT (NUMBER)	ROUTE	SLT* (SECONDS)	POSITION (NMI)	MEASURED FROM	CURRENT IAS (KNOTS)	CURRENT ALTITUDE (FEET)
1	2	45	1.71	Touchdown	135	1000
2	1	120	4.57	Touchdown	135	2000
3	2	195	7.87	Touchdown	160	3400
4	1	270	11.5	Touchdown	170	4000
5	2	345	3.85	WP4	170	5000
6	1	420	1.43	WP3	170	5000
7	2	495	5.00	WP3	170	5000
8	1	570	4.53	WP2	200	6400
9	2	645	6.89	WP2	200	7000
10	1	720	25.72	WP1	240	7800
11	2	795	16.25	WP1	250	9000
12	1	870	15.00	WP1	250	10000
13	2	945	3.05	WP1	290	12400
14	1	1020	0.00	WP1	300	14000

* Scheduled landing times are assumed from the clock time set equal to zero at the time of surveillance failure.

NOMINAL TIME TO FLY FROM WP1 TO THE RUNWAY ON ROUTE 1 = 1020 SECONDS

NOMINAL TIME TO FLY FROM WP1 TO THE RUNWAY ON ROUTE 2 = 975 SECONDS

MINIMUM SEPARATION BETWEEN AIRCRAFT (INCLUDING BUFFER)= 75 SECONDS

75 SECONDS MINIMUM SEPARATION ON FINAL APPROACH COURSE ONLY; AIRCRAFT NOT ON FINAL MUST BE SEPARATED BY AT LEAST 3 NMI

3. Ten knots along-track wind forecast errors (cross-track wind forecasting errors are not relevant in the analysis since the aircraft's navigation system assumes responsibility of maintaining the desired track). These errors are based on the ground system values used to determine speed assignments to aircraft on the two approach routes so as to compensate for wind effects. Thus, as seen in Figure B-1, an error in along-course wind has opposite impact on aircraft on the baselegs of routes 1 and 2. The analysis accounts for this phenomenon.

4. In the traffic scenario presented in the body of the paper, all aircraft were assumed to be flying nominally at the time of surveillance failure. In order to include the effect in performance under a more realistic set of initial conditions, an initial arrivals situation (i.e., the flight variations that aircraft would have experienced under M&S control) was computed for each aircraft at their respective positions from the variation and controllability results presented in Reference 3.

5. For guidance the RNAV aircraft used MLS and VOR/DME systems. The navigation systems' error budget is presented in Table B-2. The aircraft using a VOR/DME system for guidance were assumed to be equipped with present day automatic flight control systems (AFCS) with two standard deviation accuracy of $\pm$ 3000 ft. in turns. The aircraft using MLS as the navaid were assumed to be equipped with future automatic flight control systems with two standard deviation accuracy of $\pm$ 300 ft. in turns (this is because the accuracy of a VOR/DME system does not warrant a $\pm$ 300 ft. AFCS, but a highly accurate MLS could gainfully utilize better AFCS for making smoother turns and flying curved approaches).

The landing time deviations due to variations in speed and aircrafts' ability to maintain a desired track depend on the individual aircraft and its pilot. Also, the initial arrival deviations at the time of surveillance failure depend upon the respective position of each aircraft (i.e., how much distance an aircraft has been flying since the last M&S command). All of these deviations are assumed to be normally distributed with zero means and some standard deviations, which can be combined in the root sum square (RSS) to yield an effective overall distribution. From the individual deviations in landing times of aircraft, interarrival time variations between successive pair of aircraft were derived.

The effect of wind varies over different sections of the approach routes. The effect of along-track winds on the downwind legs and

TABLE B-2

NAVIGATION SYSTEMS ERROR BUDGET

SYSTEM	ERROR COMPONENT	±2σ ERROR
VOR	Airborne Receiver	1.0 Deg
	Ground Station	0.5 Deg
	Multipath	1.0 Deg
	Total (RSS)	1.5 Deg
DME	Airborne Receiver	0.2 nmi
	Ground Station	0.1 nmi
	Fluctuations	0.1 nmi
	Total (RSS)	0.25 nmi
MLS [Long Range Accuracy*]	Azimuth (Bias)	0.132 Deg
	Azimuth (Noise)	0.182 Deg
	Total (RSS)	0.224 Deg
	Range (Bias)	93.6 Ft.
	Range (Noise)	24.4 Ft.
	Total (RSS)	96.8 Ft.

* Best estimates, as quoted in Reference 3.

the final approach was not considered in the analysis since all the aircraft would get the same bias effect due to winds. The only place where the winds would be effective is on the baselegs, where, in the case of two aircraft flying on their respective baselegs of the two routes shown in Figure B-1, the wind would tend to slow down one aircraft by some amount while the other aircraft would get the same amount of increase in its speed. This implies that if both the aircraft were flying a ground speed of Vg, their speeds under the influence of winds equivalent to Δw knots would respectively be:

$$Vg_1 \text{ (A/C 1)} = Vg - \Delta w \qquad \text{(B-1)}$$

$$Vg_2 \text{ (A/C 2)} = Vg + \Delta w \qquad \text{(B-2)}$$

The change in landing time under the influence of winds τ_w (for a pair of aircraft approaching the final course from opposite directions) over a distance D is given by

$$\tau_w = \frac{2D\ \Delta w}{Vg^2 - \Delta w^2} \qquad \text{(B-3)}$$

The above expression for time variations due to winds is nonlinear and cannot be expressed in terms of any normal distribution. Since Δw^2 is very small as compared to Vg^2 (e.g., 5^2 vs. 180^2) the above expression can be linearized as

$$\tau_w \approx \frac{2D\ \Delta w}{Vg^2} \qquad \text{(B-4)}$$

If the variations Δw are assumed to be random and follow a normal distribution having a zero mean and standard deviation σ_w, then the effective time variation τ_w can be defined as a normally distributed random bias with a zero mean and standard deviation given by the equation

$$\sigma_{\tau\omega} = \frac{2D\ \sigma_\omega}{Vg^2} \qquad \text{(B-5)}$$

In the case of worst case performance the winds would tend to increase the interarrival time variations between aircraft pairs. Hence, the above mentioned deviations due to winds were statistically combined with the interarrival time variations described earlier. These interarrival time variations are then translated into distance variations on the final approach using an average final ground speed of 140 knots.

Since the scheduled landing times of aircraft were established by the M&S system based on the buffer size related to the delivery accuracy of the system before the surveillance failure, the separations that would be achieved between successive pairs of aircraft (after taking into consideration the distance variations caused by surveillance outage) were computed so that 97.5% of the aircraft would not violate these minimums under worst conditions. The computed results (presented in Section 4) indicate how many aircraft should be permitted to land after the surveillance outage so that a certain minimum separation threshold will not be violated.

It can be shown that the above answers, based on a probability of .975 that the last aircraft pair's separation does not fall below calculated value, is very close to those derived from a consideration of a probability of .975 that no pair of aircraft have separation less than that calculated. This is due to fact that the errors of the last considered aircraft pair dominate those of other pairs (except for pairs on final approach in MLS case).

APPENDIX C

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APPENDIX D

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COSTS AND BENEFITS OF THE MLS TO THE MILITARY SERVICES

30 April 1976

Prepared for
Department of Defense
and
Federal Aviation Administration
Department of Transportation

PREFACE

This study presents a factual description of the benefits of an internationally accepted common civil/military Microwave Landing System (MLS) to the Military Services. It is an update and rewrite of a report of 21 March 1975 entitled, "Costs and Benefits of the NMLS to the Military Services."

For those who are familiar with the earlier report, it should be noted that there are several significant changes in the method of reporting. The Facilities and Equipment (F&E) shown in this report represents the actual costs of equipment and installations and are not amortized as was done in the earlier report. F&E costs will, therefore, build up faster and be more representative of the required military budgets. These funds are indicated at the time of implementation and would have to be budgeted one to two years prior to the dates shown.

Since the amortization was removed, no amortization was indicated for current or recent F&E funds expended by the Military Services in the procurement, modernization or installation of approach and landing system equipment. In the earlier report these funds were amortized over the expected replacement life of the equipment.

A fourth scenario has been added to the three basic scenarios shown in the 1975 study. The fourth scenario assumes a higher degree of MLS acceptance than military planners are currently willing to project. As shown, it would only impact the Navy and assumes in their case that MLS would completely replace Navy and Marine Corps automatic landing systems in tactical applications.

In this study, costs are based upon the 1976 dollar value although some of the pricing was accomplished in the latter part of 1975. No provision is made for inflation or changes in the value of the dollar over the period of equipment phase in and phase out. In fact, it is not reasonable to consider savings entirely on the basis of the dollar value in any one year.

This is due to the fact that savings are in terms of personnel reductions and costs are in terms of electronic equipment purchased. Present rapid changes in the state of the electronics art could cause these costs to be reduced. Personnel cost savings can be expected to increase at about the same rate as the value of the dollar decreases.

Inputs were obtained from many sources. Information pertaining to implementation plans was obtained from the separate services. MLS equipment costs were obtained from FAA and Special Committee 125 of the Radio Technical Commission for Aeronautics (RTCA). MLS installation costs are based upon experience with similar systems in the military environment. Operation and Maintenance (O&M costs were obtained from various military sources and the same costs applied to like units in all Services.) For example, one manning level was applied for all Precision Approach Radars with two display console positions, in spite of the fact that manning doctrine may vary among the Services.

This study describes benefits which can be quantified in terms of cost savings and benefits to operations of the Military Services which are difficult or impossible to quantify in terms of cost savings. For the costs and savings that are quantified here, a ±20% confidence factor goal was established. It is believed that this goal has been achieved. To do this, the same information was obtained from several sources. As could be expected, there was some variance in the numbers obtained. If information from two or more sources agreed sufficiently to yield an output within the established goal no further inputs were requested. No claim is made that numbers used will agree with any one source. Where information from several sources failed to agree, sources were questioned further and additional sources were interrogated until a general consensus was obtained or an understanding was reached of the qualification required in using the numbers.

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ACKNOWLEDGEMENTS

It would be impossible to have performed this study without help from many sources. Appendix G is a partial list of the persons contacted during this and previous studies on this subject.

We acknowledge inputs from RTCA Special Committee SC-125 and in particular the information obtained from the Informal Military Planning and Costs Group chaired by LTC D. Goodson, the Informal Civil Costs Group chaired by Mr. R. Jacks and the Informal Benefits Group chaired by Mr. O. Lietzke. It was not always possible to use this source information directly but it served to show that we were within our confidence factor goal of ±20 percent.

For example, LTC Goodson's Group showed a total of 203 fixed base CAT II MLS installations. This study shows 214 installations; however our number includes 13 additional MLS installations recently projected by the Navy to cover runway ends now supported by GCA/PAR units on a turntable. Also the Informal Military Planning and Cost Group showed a total of 22,740 aircraft. Our number, 20,330, is based upon Military Aviation Forecasts Report No. FAA-AVP-75-12 of September 1975 published by the Federal Aviation Administration. Our number represents a prediction of active military aircraft operating in the Continental United States in 1987 and could be in error by 10 percent. The Forecast was used because it provided a published breakdown of aircraft by services and by general class--jet, turboprop and piston. The report of LTC Goodson's Group has been valuable in showing a close correlation between the numbers used in this report and those provided to SC-125.

The prices for MLS ground and airborne sets was derived from the output of Mr. Jacks' Group plus our own estimates for tactical and shipboard MLS equipment and for installation of airborne equipment in military aircraft. Mr. Jacks cost figures are in some variance with numbers provided later by Mr. J. Kouchakdjian of FAA. Our figures are somewhat lower than Mr. Kouchakdjian's possibly because we did not include marker beacons and our

installation supervision ran a little lower. Our estimates for ground equipment and installation, derived from Mr. Jacks report were within 10 percent of Mr. Kouchadkjian's estimates.

Our estimates for airborne MLS equipment were derived from Mr. Jacks' report. In this case we were faced with selecting the pieces which might be installed in various military aircraft. The rationale for selection of various MLS modules and a breakdown of airborne pricing appears in Appendix F.

Many of the MLS benefits, which should exist but which we did not attempt to quantify as cost benefits, derive from the work of Mr. Lietzke's Informal Benefits Group.

Another contributor, whose work we acknowledge, is Mr. J. Ennis of the Naval Weapons Engineering Support Activity, Cost Management Division. Mr. Ennis is in the early stages of developing a life cycle cost analysis model for Navy implementation of MLS. At this point in time we were only able to compare Operation and Maintenance figures in which Mr. Ennis has little confidence (±50%). On the newer numbers which have not been run through the computer we seem to correlate quite closely on maintenance but differ considerably on the cost of operations. This is due in part to the fact that we used Navy generated, DOD approved, pay scales which include cost of training along with medical care, retirement, etc., as part of the cost per man. The biggest difference between Mr. Ennis and our operations costs is in the number of GCA/PAR operators used. We based our number of operators upon USAF crews with an average of 16 hours per day operations. Mr. Ennis shows an average of 16.6 operators per unit, we show 6. We show O&M for a CPN-4A at $319.6K per year. While Mr. Ennis had not run a new total at our cut off date, he stated that his CPN-4A cost appeared to be about double ours. Since we were unable to reconcile this difference in the number of operators, 16.6 versus 6, we used our O&M cost of $319.6K per unit per year.

Mr. R. Lehto and Mr. W. Holliman of the Bureau of Naval Personnel supplied updated personnel costs for enlisted personnel we used in calculating the Operation and Maintenance for all the Military Services. We were advised by Mr. K. Peterson of Department of Defense, Office of Manpower and Reserve Activities that the personnel cost figures developed by the Navy were the best available for the type of study we were performing. The personnel costs represent a reduction of about $1000 a man from our report of a year ago. We assume that the actual costs have not gone down but that a new computer iteration has produced figures with a higher confidence factor.

In attempting to establish phase out/phase in plans of the services, which can only be approximations at best and are subject to such unpredictabilities as MLS availability dates, availability of funds and changes in the defense posture, we contacted and acknowledge the assistance of the following persons:

ARMY

LTC W. Johnson	Office of Dep. Chief of Staff, Research, Development and Acquisition
Mr. J. McKeeman	Army Aeronautical Services Office
LTC C. Phillips	Federal Aviation Administration (USA Liaison)

NAVY

CAPT Ortega	Office of Dep. Chief of Naval Operations (Air Warfare)
Mr. D. Tuttle	Office of Dep. Chief of Naval Operations (Air Warfare)
Mr. C. Taylor	Naval Air Systems Command
Mr. W. Raynor	Naval Electronics Systems Command
Mr. G. Miller	Naval Electronics Systems Command
Miss E. Bibb	Naval Electronics Systems Command
CAPT G. Groehn	Federal Aviation Administration (USN Liaison)

AIR FORCE

COL J. Diven	Office of Dep. Chief of Staff, Plans and Operations
MAJ R. Brady	Office of Dep. Chief of Staff, Plans and Operations

LTC D. Goodson	Office of Dep. Chief of Staff, Research and Development
LTC G. Wendland	Federal Aviation Administration (USAF Liaison)

MARINE CORPS

CAPT A. Warnack	Marine Corps Headquarters, Requirements and Programs Division
Mr. Thomas	Marine Corps Development Center, Air Branch (Quantico, Virginia)

SECTION I

INTRODUCTION

MILITARY LANDING SYSTEM HISTORY

Military approach and landing systems received a major impetus during World War II when a large number of hastily trained pilots were required to fly in bad weather. At the end of the war two "landing" systems were operational: Ground Controlled Approach (GCA) and Instrument Landing System (ILS). In Congressional hearings held following the war, the Navy stated a policy of using GCA largely based upon the limited pilot training and indoctrination required. The Air Force primary means of aircraft IFR recovery was also GCA during this period.

Since World War II, the Military Services maintained GCA as the primary IFR recovery system. However, in 1968, Air Force policy dictated use of ILS as its primary IFR recovery system. The term GCA is generally used to include an Air Surveillance Radar (ASR) for air traffic control and a Precision Approach Radar (PAR) for landing. This study considers only the PAR portion of the GCA. In a PAR, a landing controller determines the aircraft's deviation from the proper lateral and vertical approach paths by observing a radar display. The landing controller tells the pilot to "fly left", "fly right", "increase his rate of descent" or "decrease his rate of descent" to make the proper landing approach. This is referred to as a "talk down" system. In ILS, position relative to the proper approach path is air derived and displayed to the pilot on a cockpit instrument. Horizontal displacement is shown on a vertical needle and vertical displacement on a horizontal needle. The display is referred to as a crosspointer indicator. When both needles pass through the center of the indicator, the aircraft is on the proper approach path.

MILITARY ROLES AND MISSIONS

Military flying includes every type of operations. As examples: The Army and Marine Corps make extensive use of helicopters operating from small clearings in forward areas. The

Marine Corps uses this type of clearing for high performance vertical take-off and landing (VTOL) attack aircraft which will also operate from a small aircraft carrier. The Navy and Marine Corps also operate supersonic jet aircraft from aircraft carriers and the Marine Corps flies these same aircraft from small airfields for tactical support (SATS) with a 2000-foot runway. The Air Force operates large transports, such as the C-130 from short runways and relatively unprepared landing areas. The Navy launches and recovers anti-submarine warfare (ASW) helicopter aboard destroyers. All of this is in addition to the operation of subsonic and supersonic aircraft from conventional runways of 5000 to 15000 feet.

The operation of military aircraft is mission oriented. The Army aircraft are used in forward areas to move troops, supply gun fire power, direct artillery fire and provide logistic support. Navy carrier aircraft provide fighter aircraft defense, bombing support, reconnaissance, electronics countermeasures and ASW support. The Air Force in addition to fighter and bomber operations supplies attack support for the Army in forward areas and logistic support--men and materials--for all services world-wide.

The most serious problems occur in the forward areas where aircraft of all services and with widely varying flight characteristics must operate in close cooperation for air traffic control and landing. In actual operations to date, GCA and the PAR portion of GCA have been the common denominator of the services. ILS cannot be expected to perform properly except at carefully prepared sites and has therefore not been used in forward areas. The desire to have a system which would remove the ground controller from the landing system loop and which would fulfill the peculiar requirements of a specific mission has led to extensive research and development in each of the military services. At one point more than 40 different development efforts were identified although this included FAA efforts and GCA improvements. These developments varied from simple man-transportable systems for helicopter landing in forward areas to the Navys' highly sophisticated system for automatic landing of supersonic aircraft aboard an aircraft carrier. These two requirements have been satisfied; however, in meeting specific operational requirements, many systems were tried and found wanting. During this period, contractors were able to sell separate so-called "proprietary" developments to each of the Services and to FAA even though tests by one of the agencies may have shown the system had serious limitations.

RESEARCH AND DEVELOPMENT

The advent of the MLS program and the promise of common civil/military interoperability, both nationally and internationally, has served to reduce landing system research and development (R&D) by the Military Services for new systems.

Present planning for military R&D is largely in support of the MLS program. Funds are required to procure, test and evaluate special ground, shipboard and aircraft hardware which is designed to operate in the military environment. It should be noted that test and evaluation funding can be considered as continuing and is therefore not included in cost figures provided herein. These funds are in support of Army, Navy and Air Force laboratories such as the Army ECOM effort at Fort Monmouth, the Naval Electronics System Test and Evaluation Detachment (NESTED) and Naval Air Test Center (NATC) Flight Test at Patuxent River, and the Air Force Flight Dynamics Laboratory at Wright-Patterson Air Force Base, Dayton, Ohio. These laboratory and Flight Test Organizations determine siting requirements, prototype aircraft installations and test the capabilities and limitations of any new or modified landing system. Funding for these activities would not be changed significantly with or without MLS.

Limited R&D is continuing to complete work on several systems that have been approved for service use and are being procured in limited production quantities. These systems (See Appendix A for brief description) include the Air Force's TPN-19 and GPN-XX, the Marine Corps' TPN-22 and MRAALS as well as reliability improvements to PAR and ILS equipment for all

Services. Limited production has been justified on the basis that military needs cannot be satisfied by MLS prior to 1982 and these limited procurements will provide a cost effective improvement in operational capability for the interim and during the transition to MLS.

STATUS AND PROJECTED PLANNING

The all-weather approach and landing system capabilities of the Military Services vary widely. All Services have placed heavy reliance in Precision Approach Radars (PARs) because this system requires no special airborne installation and very little pilot training. The Navy because of its unique ship/shore operations requires and has obtained Category III capability for its first line high performance Navy and Marine Corps aircraft. All other aircraft have or are getting Category I or II capability. The Navy uses its own ship/shore systems and does not maintain commonality with other services or civil aviation; however, long range patrol and support aircraft are equipped with ILS receivers. The Air Force requires civil aviation commonality for its aircraft and makes extensive use of ILS. While few airports are certified for Category III operations the C-5 aircraft is certified to make automatic landings. The C-141 and a few combat type aircraft are scheduled to get a Category III capability. New and improved PARs should provide all Air Force aircraft with a Category I and in some cases a Category II capability. The Army depends almost entirely on PARs for operations in bad weather. Because the preponderance of Army aircraft are helicopters with slow approach speeds, it is possible in most cases to operate to Category II minimums using a PAR.

The current status and future plans for each of the Services are summarized below:

ARMY -- The Army currently uses PARs, voice communications and low frequency non-directional beacons for aircraft (mostly helicopter) approaches. ILS is installed at a few of the larger bases and is used primarily for training purposes. A split-site tactical landing system (TLS) using microwave scanning beam principles has been developed for use by helicopters.

NAVY -- The Navy currently uses the SPN-42 Automatic Carrier Landing System, the SPN-41 scanning beam microwave landing system, and PARs to provide an all-weather capability for their aircraft. The Marine Corps is procuring the TPN-22, an equivalent of the SPN-42, for their Marine Air Traffic Control and Landing System (MATCALS) and a man-transportable equivalent of the SPN-41 as the Marine Remote Area Approach and Landing System (MRAALS). The Marine Corps also makes extensive use of mobile and transportable PARs. To improve the performance and reliability of both Navy and Marine Corps PARs, a modernization program was instituted more than five years ago. The goal of this program is to switch PARs to solid state circuitry and to remote operator positions into the control tower at many locations. This program was accelerated recently when Iran purchased solid state PARs and picked up most of the non-recurring production start-up costs. Airborne compatibility is maintained by using the ASW-25 and ASW-27 data link equipment for both the SPN-42 and TPN-22 and the ARA-63 receiver for the SPN-41 and MRAALS. As stated earlier PARs require only ground to air voice communications. The Navy operates a few ILS equipments for training and special purposes; most long range patrol and cargo aircraft have airborne ILS equipment for operations at civilian airbases and in host countries.

The Navy and Marine Corps in their own ship and shore environment do not anticipate any improvement in operational capability with the advent of MLS. The principal advantages will stem from compatibility with other civil and military services world-wide and from the elimination of at least 59 PARs and 590 operator billets. The Navy and Marine Corps propose to replace SPN-41/TRN-28 and MRAALS with equivalent MLS capability and will consider modifying existing hardware as soon as the new signal format has been approved by ICAO and NATO countries. Navy's SPN-42 and Marine Corps TPN-22 (automatic landing systems) are planned to continue in operation for an indefinite time. MLS proven performance, however, could change this planning.

AIR FORCE -- The Air Force currently uses both ILS and PAR equipment. They have also procured some microwave TALAR systems largely for their C-130 fleet operating from combat zones but the equipment was not installed prior to the end of the war in Vietnam and is not significantly employed. The Air Force has procured solid state ILS equipment and is installing it with a view to improving ILS reliability and decommissioning some PARs. ILS siting problems and installation costs will limit the extent to which PARs can be replaced. In a program similar to the Navy's, the Air Force is planning to modernize and update existing PAR equipment. The Air Force is also procuring new TPN-19 PARs on a limited basis. Prior to the advent of MLS, the Air Force will have increased the number of ILS installations and reduced the number of PARs. All equipment should be considerably more reliable as a result of the switch to solid state circuitry. The Air Force plans to phase-down PAR and ILS in favor of MLS starting in about 1992. The use of MLS is expected to enhance Air Force all-weather operations by providing an automatic landing, Category III, capability for certain designated aircraft.

Appendix A summarizes the current and future numbers of ground, shipboard and aircraft installations in operations or planned by the Services.

SECTION II

COST OF MLS

The method by which the Military Services implement a Microwave Landing System program will have an impact on costs which may accrue to the Department of Defense. While the Services are planning an extensive MLS program, they will be reluctant to commit funds prior to an extensive field test program and system acceptance by the International Civil Aviation Organization (ICAO). Until there is international acceptance of a Microwave Landing System and proven performance there are a number of possible situations which face the Military Services. This report will confine itself to three to four possible situations or scenarios. Each scenario represents a possible plan in which the Military Services implement MLS or uses existing and developing aircraft landing systems. There could be additional plans, however, the ones contained herein are believed representative of possible courses of action.

Scenario A assumes the MLS timetable is met; that ICAO and NATO acceptances are achieved; that procurement funds are available when needed; and implementation can start in the early 1980's.

Scenario B assumes there is no MLS; there is no ICAO standard, and; that the Military Services are left to their own resources.

Scenario C is the same as Scenario A except it assumes that the MLS timetable is slipped five years.

Scenario D is applicable to the Navy/Marine Corps only. In addition to Scenario A assumptions, it assumes the MLS capability has been demonstrated and is shown to be as good and possibly better than any Navy/Marine Corps existing or developing aircraft landing systems.

General comments applicable to all scenarios are:

1. The Acknowledgements Section of this report contains sources of information for phase out/phase in schedules, equipment, installation, and O&M costs.

2. F&E and O&M costs run concurrently with phase out/phase in schedules. No attempt is made to show procurement expenditures prior to implementation as would actually be done. F&E costs are in 1976 dollars and are not amortized.

3. Personnel increases and decreases were computed based on the number of equipments or locations and the manning table shown in Appendix B.

4. F&E and O&M costs were computed using data contained in Tables One, Two and Three. Data in these tables were derived in part from Appendices B, C, D and Table Four. Appendix F contains MLS ground and aircraft equipment definitions.

5. The considerable cost of operating military laboratories and avionic test facilities used in the test and evaluation of past, present and future aircraft landing systems will not change materially under any of the scenarios and is therefore not included in cost figures.

6. It is possible that an L-band terminal distance measuring equipment (DME) will be added to programmed military landing system inventory to remove the requirement for off-station marker beacons. The Marine Corps MRAALS includes this DME. Cost of this DME hardware, its installation, operation and maintenance are not included herein.

7. Additional costs associated with the upgrade of any approach and landing environment from the equivalent of CAT I will be encountered whether it be ILS or MLS. It is certain that to achieve the greater landing assurance of MLS over ILS, the visual cues afforded by more sophisticated approach and landing lighting must be provided to accommodate the V-STOL aircraft at heliports and on shorter runways. There is wide diversity of lighting systems which will present themselves in the various upgrade programs of airfields, necessitating substantial funding support. This element of expense is recognized but cannot be dealt with on a cost specific basis because of the wide variations in construction needs and the attendant expense associated with expanded lighting systems.

COMPUTATIONS

The Charts that follow in this section are intended to display O&M/F&E/R&D costs and personnel requirements for each scenario. Line charts are used to show equipment/system phase out - phase in by number and year. Vertical bar charts are used to show O&M/F&E costs. R&D costs are shown by a vertical bar chart and a line chart for three scenarios.

The phase out - phase in schedules for Scenario A are based upon information obtained from the Services. Air Force information was extracted from "USAF Terminal Precision Approach Control Program." Navy/Marine Corps information was obtained from several planning papers/documents including "Facility Improvement Goals" and from personnel in Naval Air and Naval Electronic Systems Commands. Army information was obtained from personnel of the Department of the Army Staff.

Appendix A contains an inventory of existing and programmed equipments and systems along with current and projected numbers. A manning table for ground and airborne equipments/systems is contained in Appendix B. Manning requirements will of course vary if ground equipment need not be available round the clock. Appendix C contains the life cycle cost of several rates and pay grade levels. These costs were obtained from a manpower model developed by the Navy (occupational standards). For consistency reasons these personnel cost figures are used for all the Services.

Appendix D shows the aircraft numbers for each Service, the expected MLS capability and aircraft Engineering Change Proposal (ECP) cost for MLS. Appendix E shows the military air fleet strengths and was extracted from DOT's military air traffic forecase 1976-1987.

Tables One, Two, Three, Four and Five show the MLS and other procurement costs, installation costs and aircraft ECP costs for figuring F&E. Also these tables show the factors necessary to compute the O&M cost of all the various programmed equipments and systems, including MLS.

Three main factors are shown in the tables for O&M. These are personnel cost, support (parts, logistics, supply, station cost) and flight inspection. Personnel costs are computed from the equipment manning table (Appendix B) and life cycle cost table (Appendix C) for the appropriate rating and pay grade level. Support costs were determined by using a percentage of initial procurement cost for parts and adding to that best estimates of available information for logistics, supply and station cost. Flight inspection costs were figured from annual FAA flight inspection data.

To determine F&E costs, for example, to equip 335 Navy aircraft with Austere MLS add unit cost ($8,000) to total installation cost per unit ($5485) and multiply by 335. Annual O&M costs were computed generally by multiplying total cost per unit per year by the number of equipments.

The following Charts are included in this section:

The Air Force portion of this study up-date has changed the estimated fleet size from 8,866 to 9,050 to adjust to the data published in the Military Aviation Forecases-Sept. 1975 for the years 1981-1987. The PAR-ILS phase-out charts and the MLS phase-in chart were designed to accommodate the estimated dates and equipment numbers presented in candidate schedules of the Terminal Precision Approach Control Program and the Military Implementation Schedule developed in the Military Informal Group at RTCA SC-125. It is recognized that none of the data represents firm planning material, therefore it has been utilized to develop as reasonable a blending of the information as was possible. The 20 tactical systems for Mobile Communication Group's deployments on contingency operations are not shown in the PAR/ILS/MLS phasing schedule but they are included in the charts depicting MLS O&M and F&E costs.

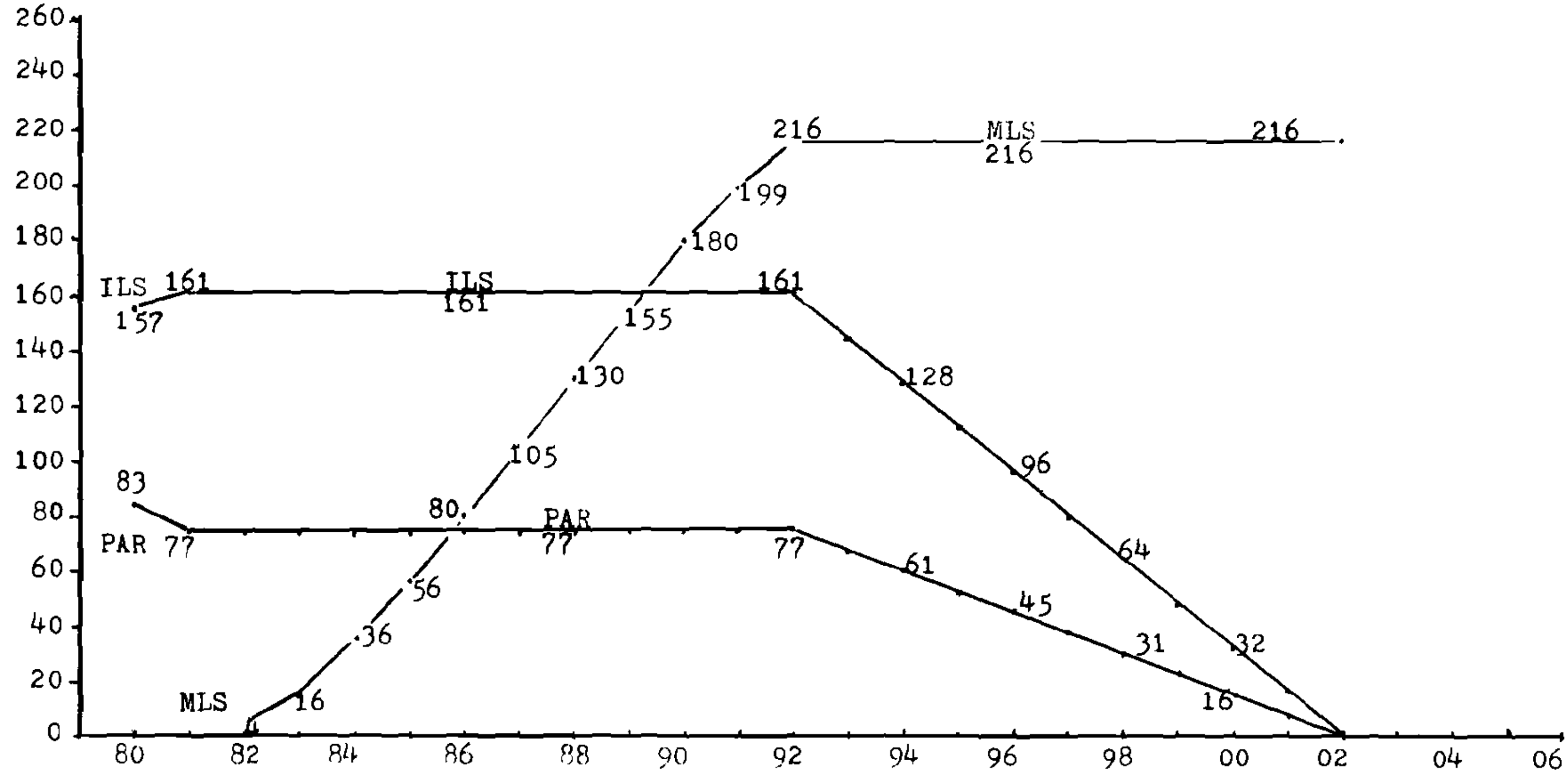
The Air Force, in Scenario A, will have stabilized its PAR/ILS posture, which will enable it to schedule MLS ground and avionic implementation over an approximate period of ten years. The PAR/ILS levels, of 77 and 161 units respectively, will be maintained until the installation and commissioning of MLS, as well as, the attendant pilot and technician training are complete. At this point, (approximately 1992) phase-down of PAR and ILS will commence and continue until approximately 2002. The technician force supporting MLS will substantially evolve from cross-training of ILS electronically oriented personnel.

The Air Force, in Scenario B will, according to the ground facility chart, merely level off and maintain the 1983 PAR and ILS facility levels at 77 and 161 respectively throughout the remaining years to 2005. There is no prospective change in avionic equipment during this scenario.

In Scenario C, the Air Force merely delays the start of PAR/ILS phase-down from 1992 to 1997 with a corresponding delay of MLS phase-in. The avionic phase-in is likewise delayed by five years.

CHART 2-1

USAF FIXED GROUND EQUIPMENTS



PERSONNEL

PAR	830	770	770	770	770	770	770	610	450	310	160	0
ILS	471	483	483	483	483	483	483	384	288	192	96	0
MLS	0	4	36	80	130	165	216	264	360	456	552	648

U.S. AIR FORCE GROUND EQUIPMENTS PHASE-OUT -- PHASE-IN

SCENARIO A - WITH MLS

U.S. AIR FORCE MLS AVIONIC PHASE IN SCHEDULE

CHART 2-2

SCENARIO A

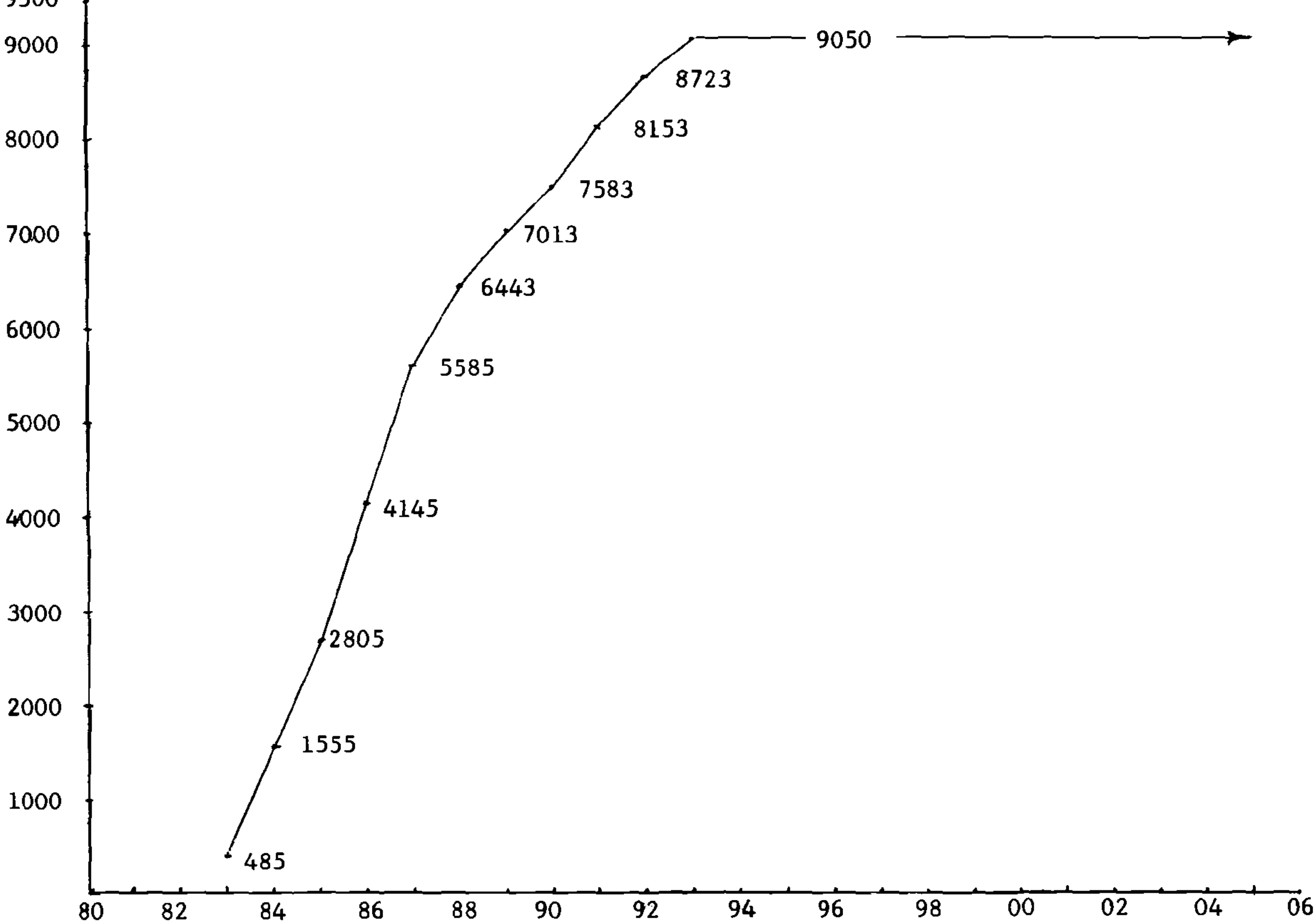
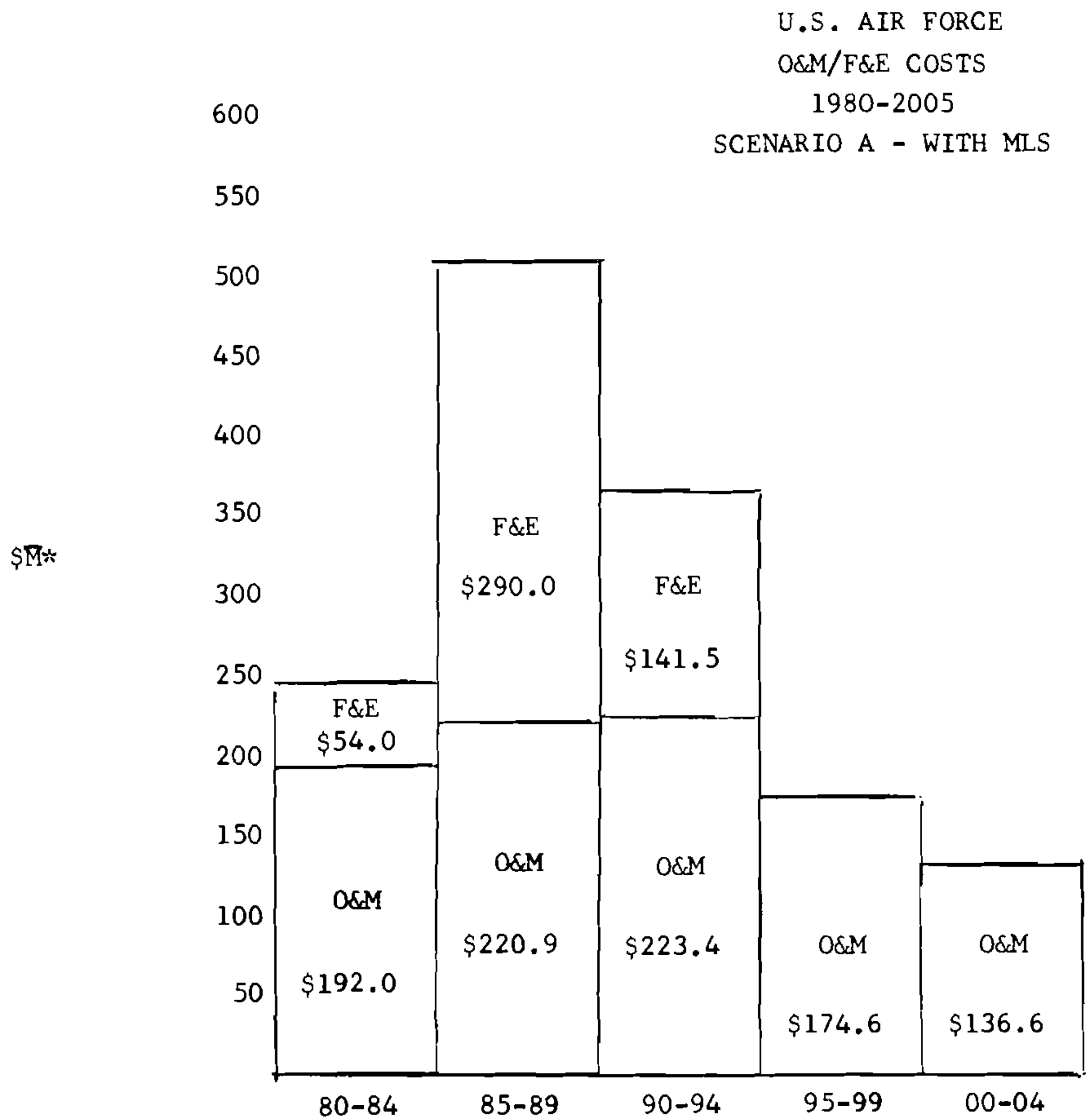
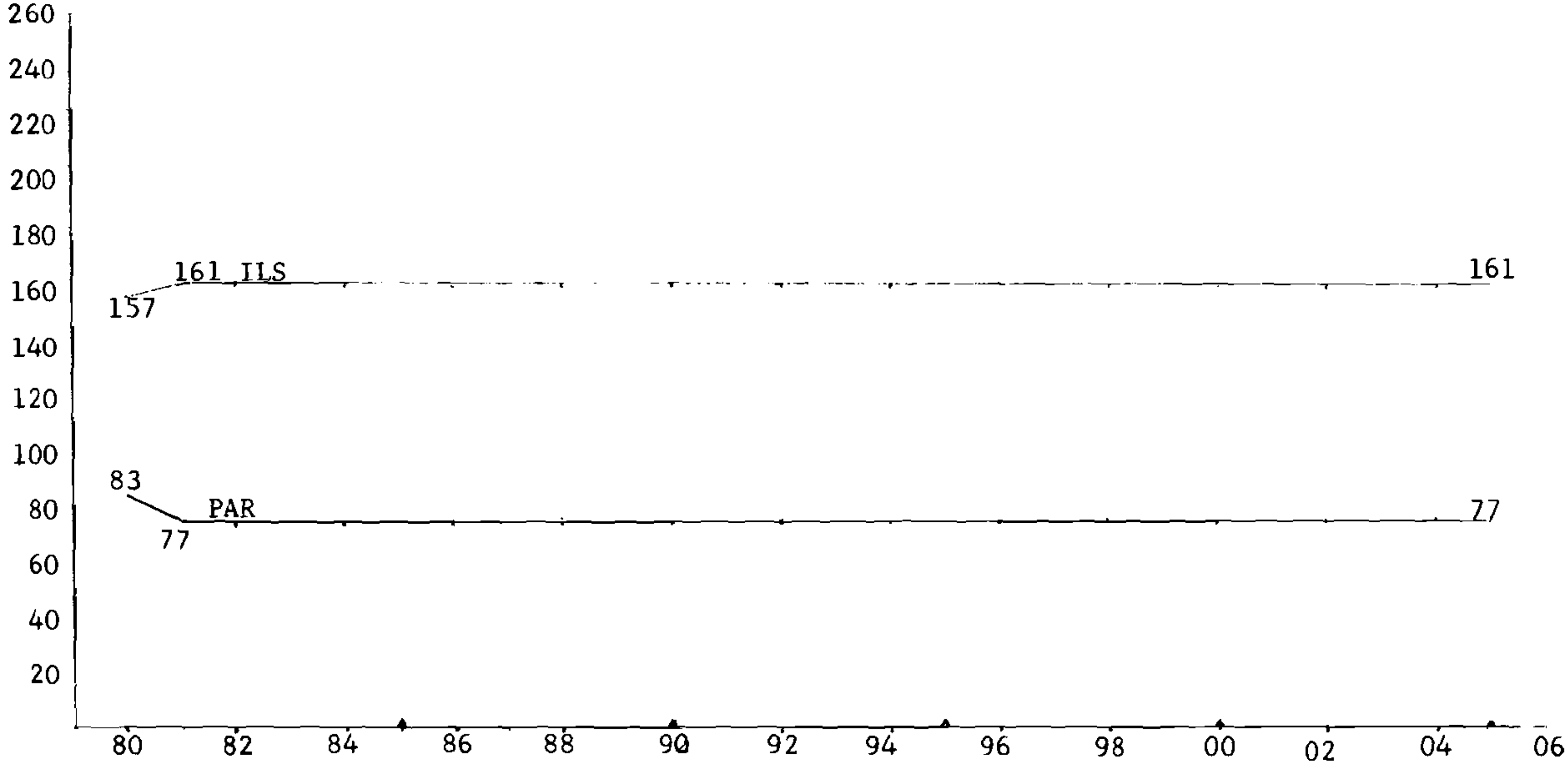


CHART 2-3



* Divide by 5 for average annual cost

CHART 2-4



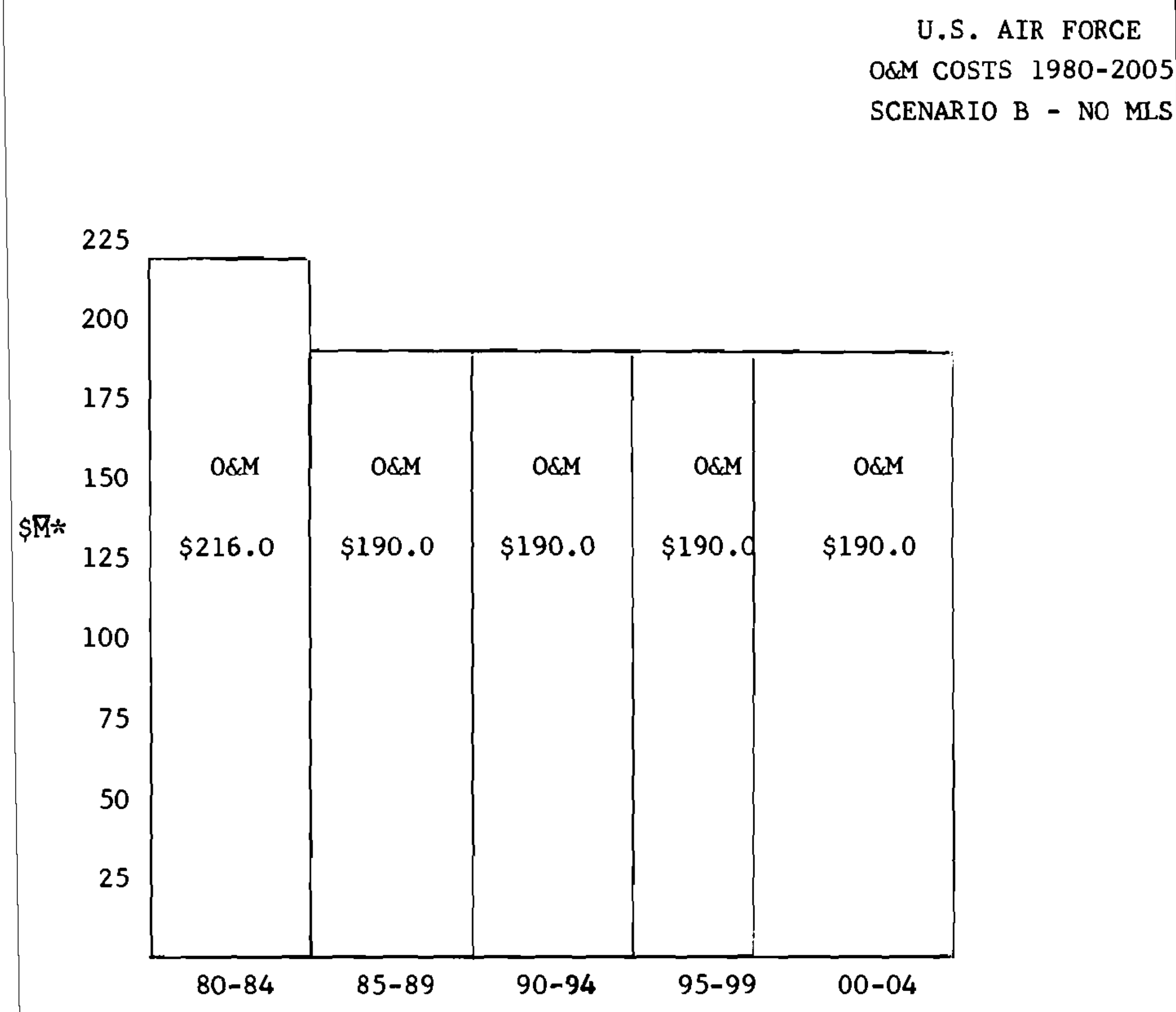
PERSONNEL

PAR	830	770	→ 770
ILS	471	483	→ 483
Total	1301	1253	→ 1253

U.S. AIR FORCE GROUND EQUIPMENTS STATUS

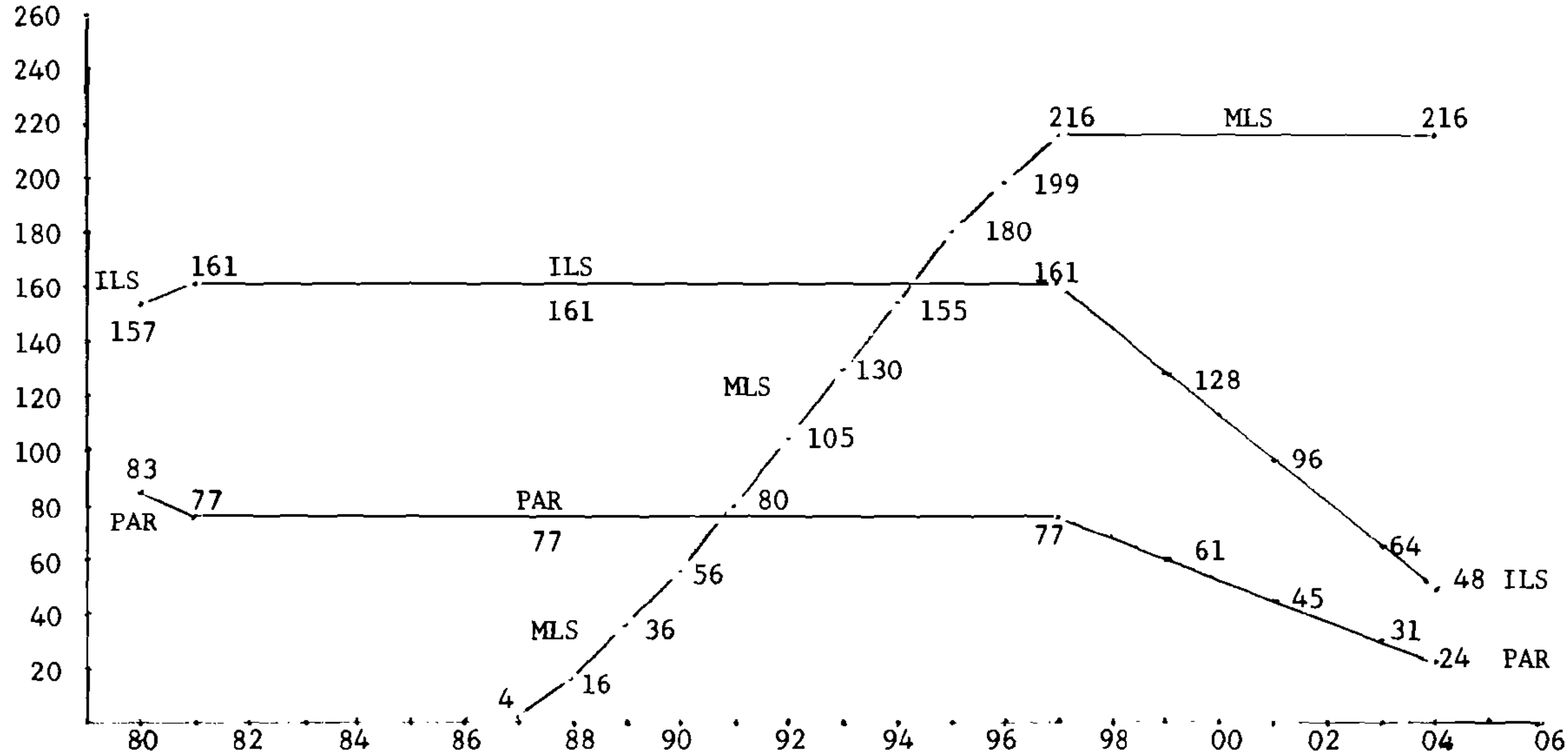
SCENARIO B - NO MLS

CHART 2-5



* Divide by 5 for average annual cost

CHART 2-6



Personnel

PAR	830	770	770	770	770	770	770	770	770	690	530	370	240
ILS	471	483	483	483	483	483	483	483	483	438	336	240	144
MLS	0	0	0	0	16	56	165	165	200	242	312	408	504

U.S. AIR FORCE GROUND EQUIPMENTS PHASE OUT -- PHASE IN

SCENARIO C - FIVE YEAR DELAY

U.S. AIR FORCE MLS AVIONIC PHASE IN SCHEDULE

SCENARIO C - MLS DELAYED 5 YEARS

CHART 2-7

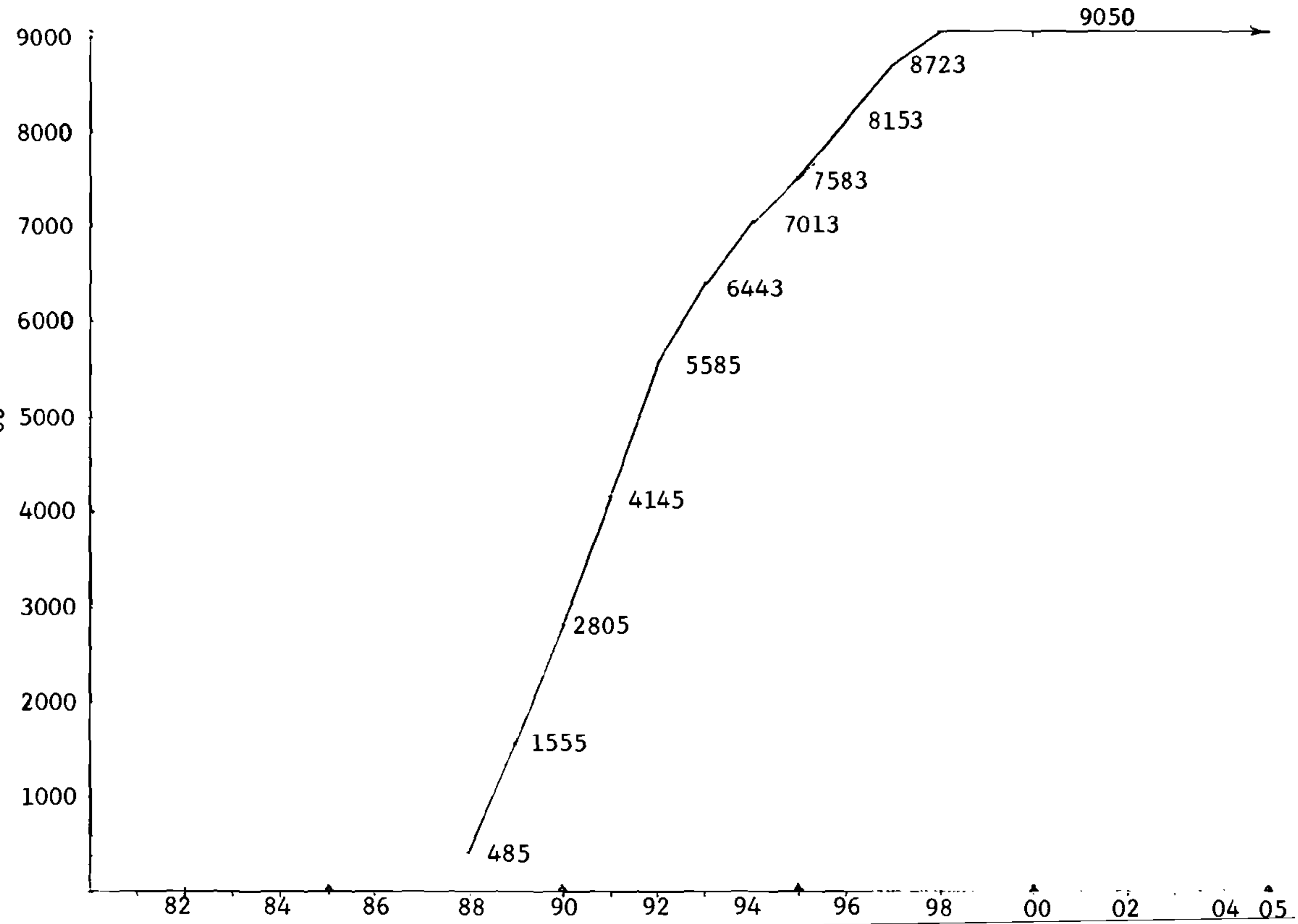
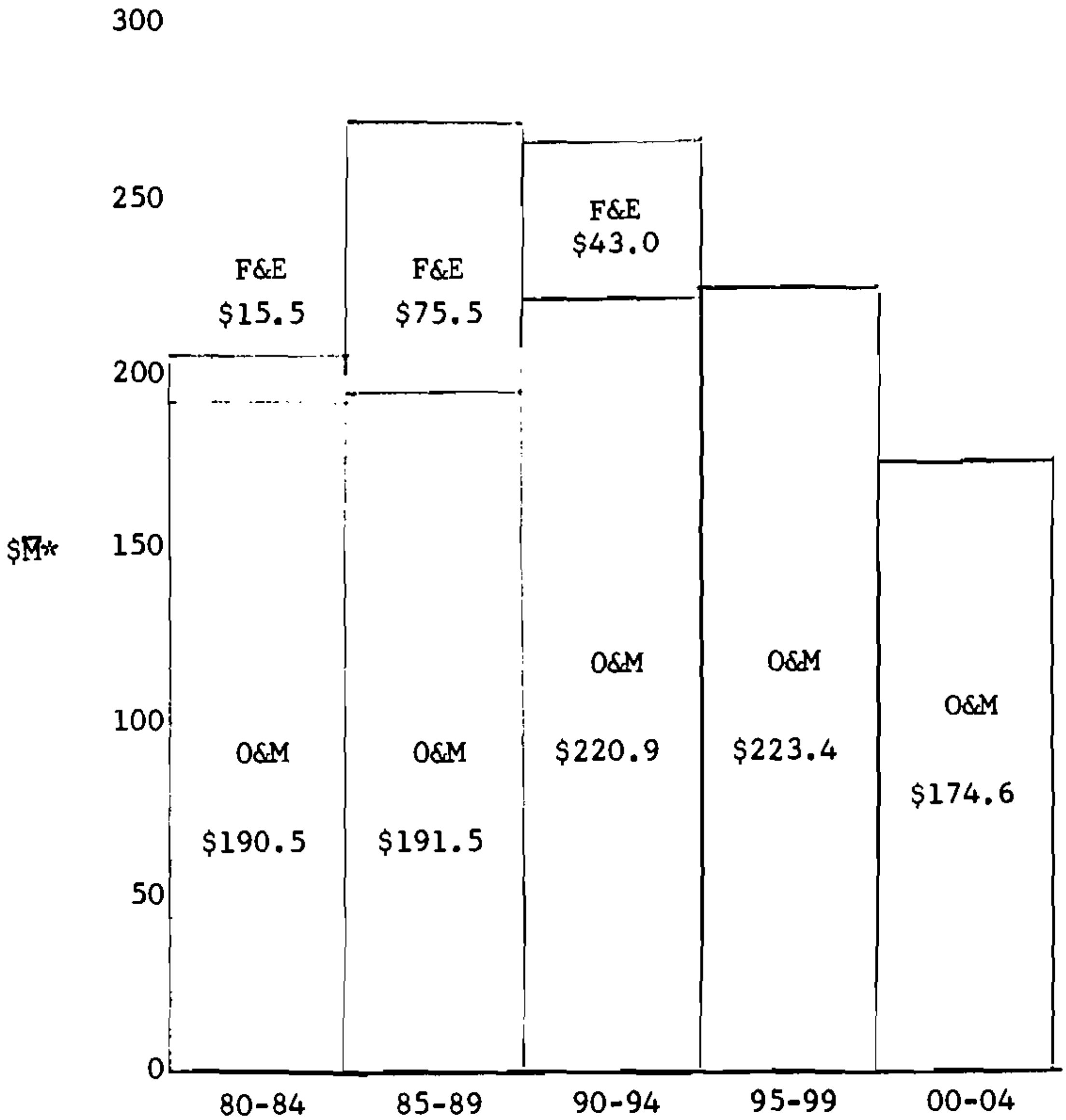


CHART 2-8

U.S. AIR FORCE
O&M & F&E COSTS
1980 - 2005
SCENARIO C - DELAYED MLS



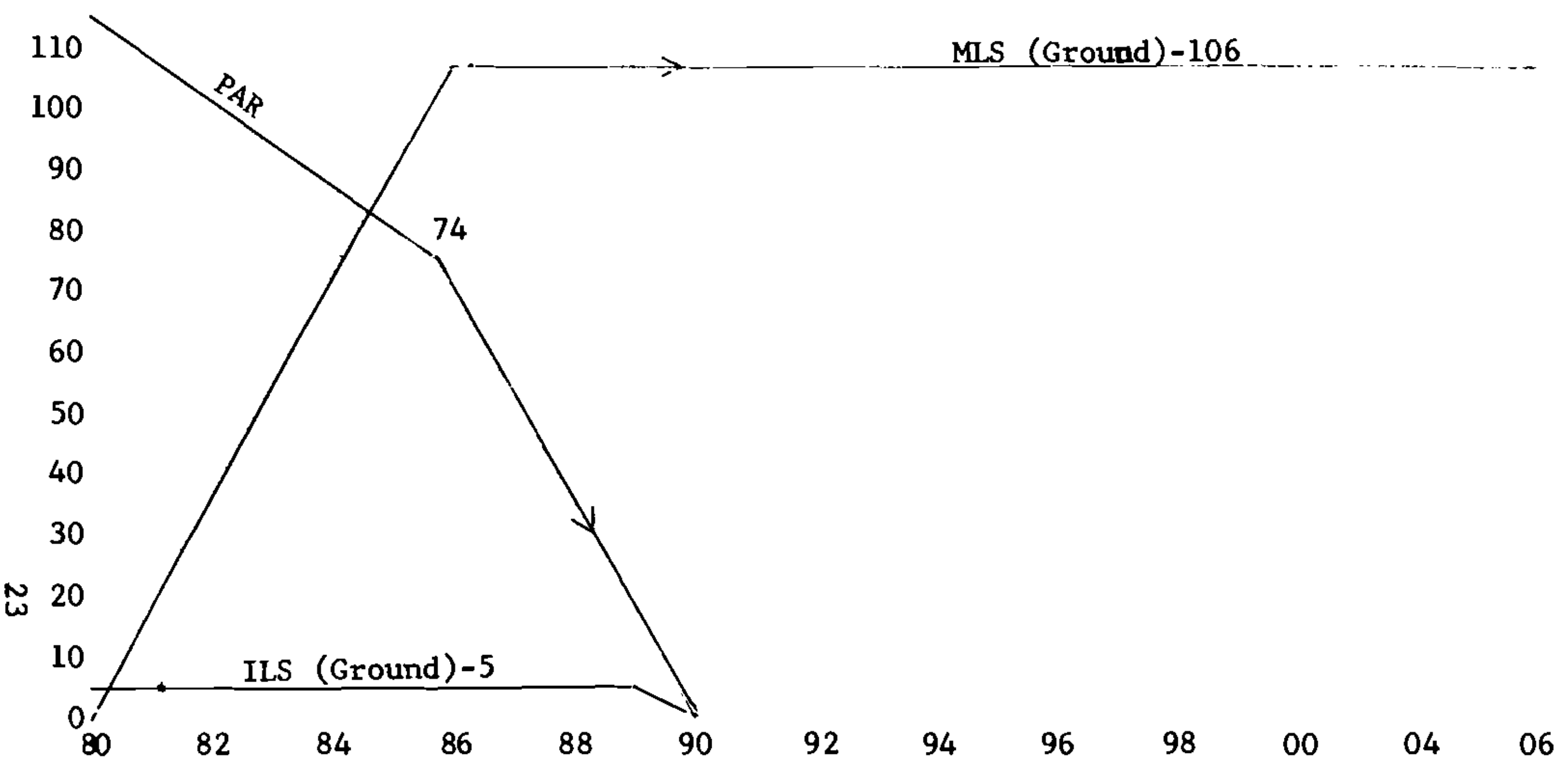
* Divide by 5 for average annual cost

ARMY EQUIPMENTS PHASE OUT - PHASE IN

SCENARIO A - WITH MLS

The Army under Scenario A would implement MLS rapidly and phase out PAR and ILS equipments so that by 1990 the O&M costs would level out at the lowest annual rate of the several scenarios.

CHART 2-9



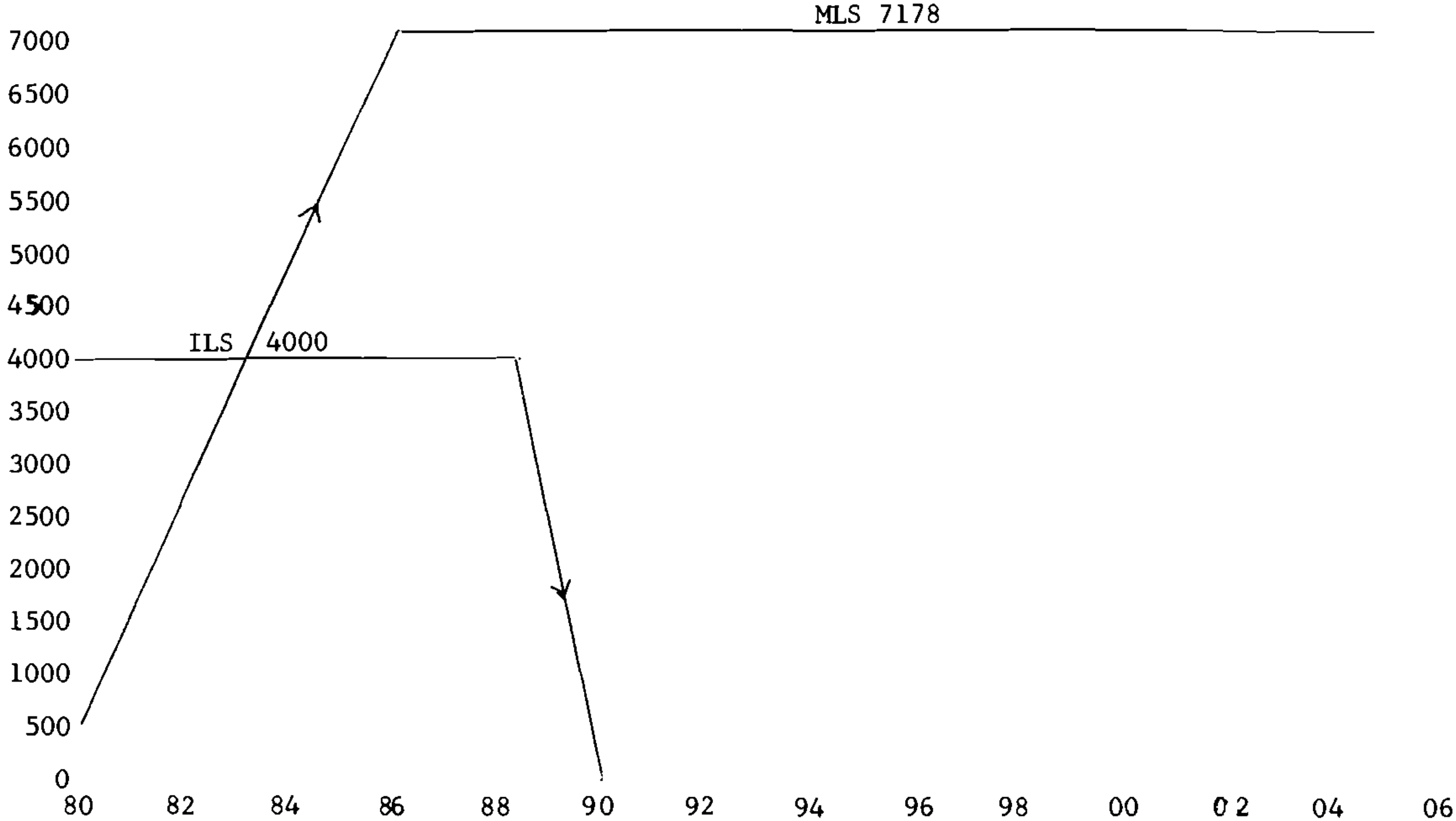
Personnel

PAR/ ILS	653	537	422	0		0	0
MLS	0	141	318		318	318	318

ARMY GROUND EQUIPMENTS PHASE OUT -- PHASE IN

SCENARIO A - WITH MLS

CHART 2-10



Personnel

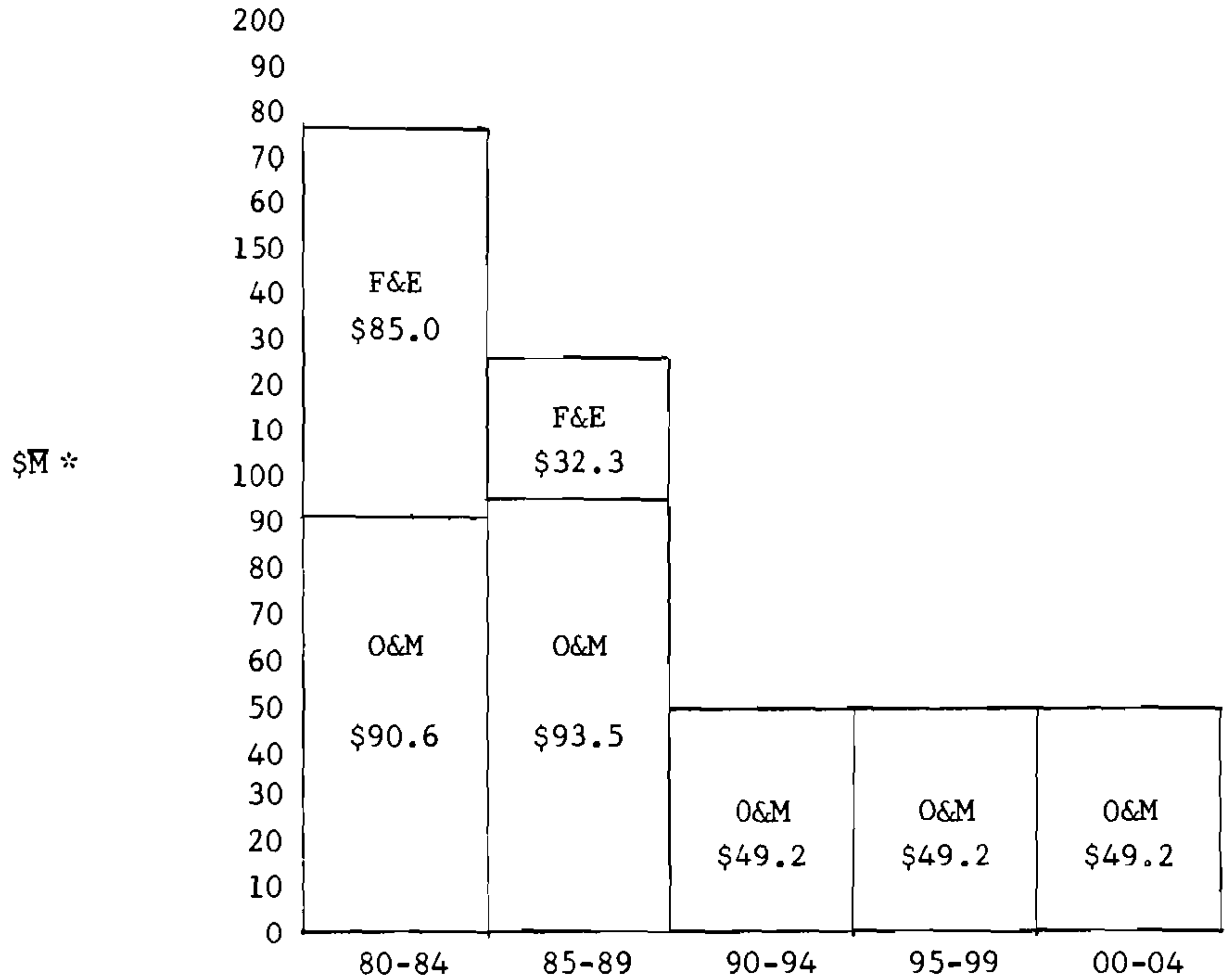
ILS	40	40	40	0	0	0	0
MLS	3	29	48	48	48	48	48

ARMY AIRCRAFT EQUIPMENTS PHASE OUT -- PHASE IN

SCENARIO A - WITH MLS

CHART 2-11

ARMY
O&M/F&E COSTS
1980-2005
SCENARIO A-WITH MLS



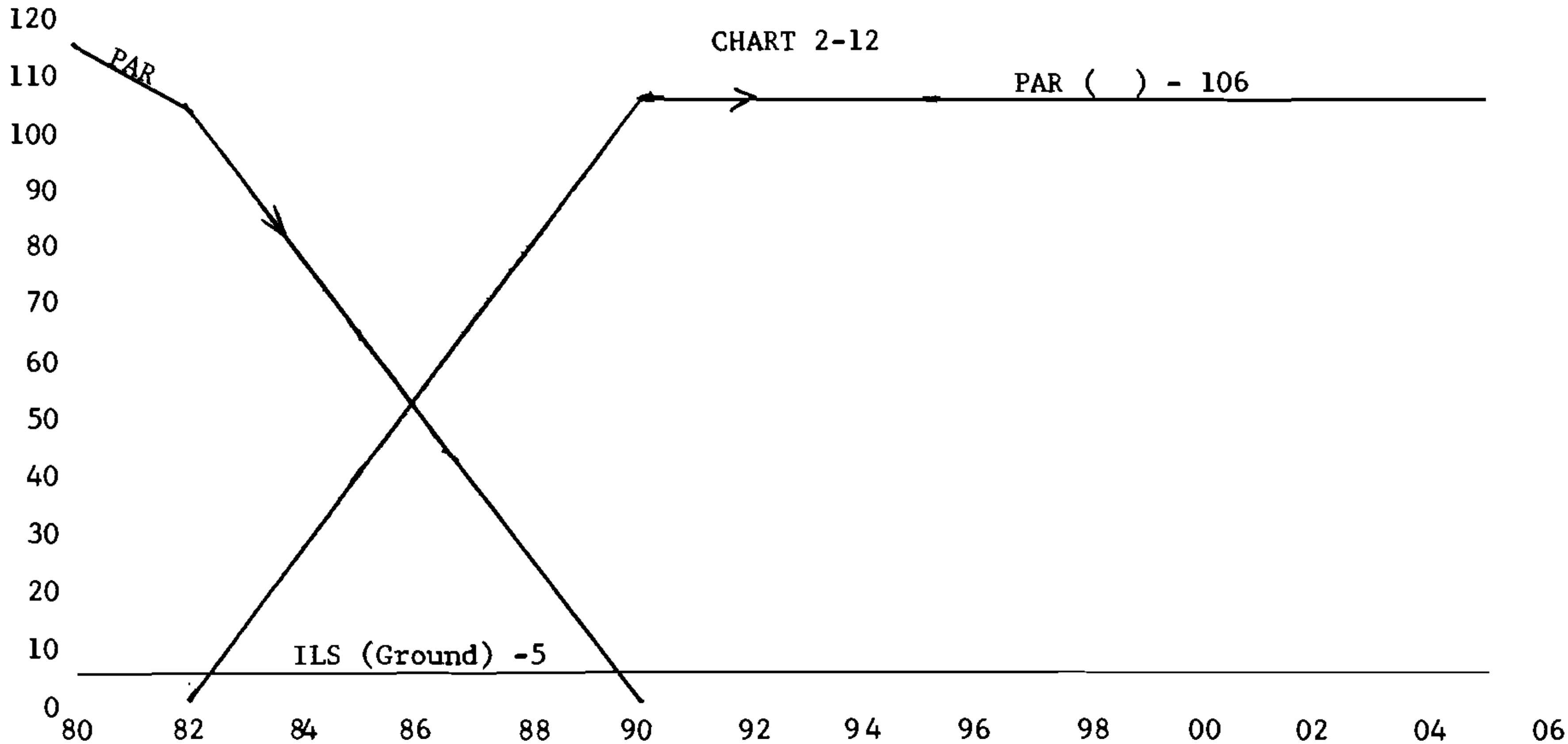
* Divide by 5 for average annual cost

ARMY EQUIPMENTS PHASE OUT - PHASE IN

SCENARIO B - NO MLS

Under Scenario B (no MLS) existing PARs which would be reaching the end of their useful lifetime, would be phased out. There are several possible replacement alternatives, however in this study the old PARs are replaced with modern low cost PARs. While the F&E costs are reduced, the O&M costs project into the future at a continuing high level. The Army's few ILS ground equipments and its airborne ILS equipments would remain in operation.

CHART 2-12



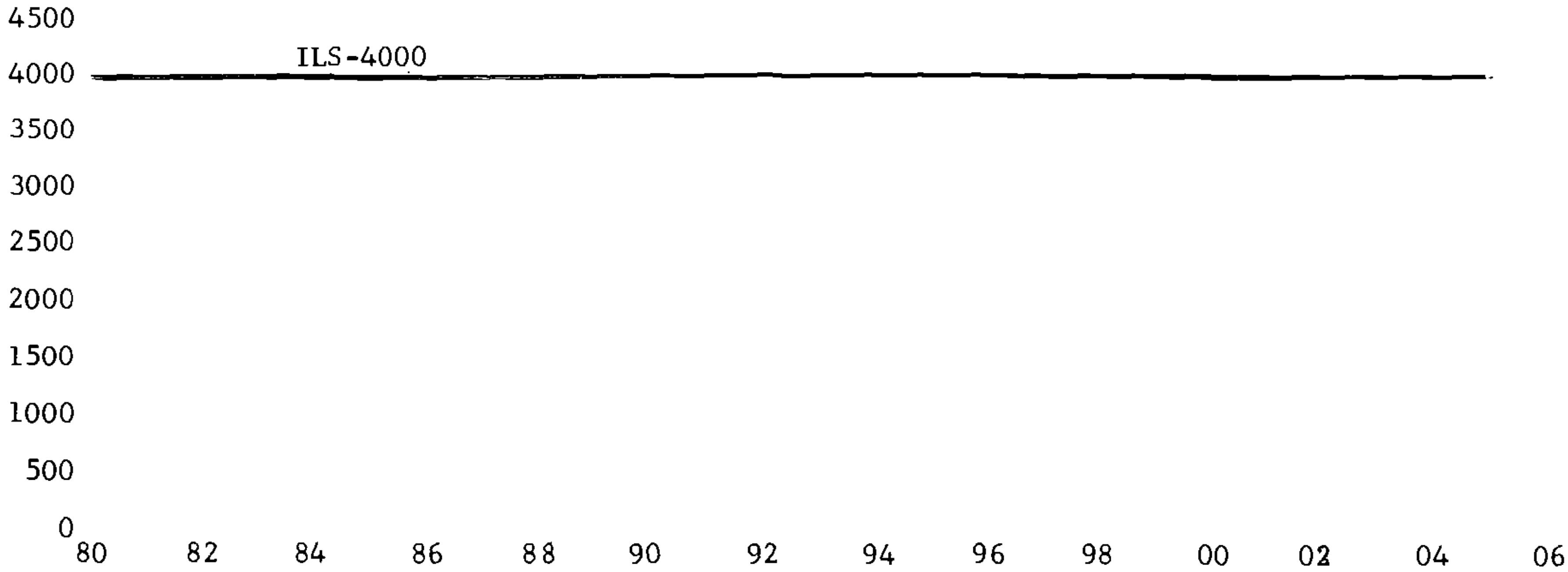
<u>Personnel</u>

PAR/ILS 653 583 583 583 583 583

ARMY GROUND EQUIPMENTS PHASE OUT -- PHASE IN

SCENARIO B - NO MLS

CHART 2-13



<u>Personnel</u>

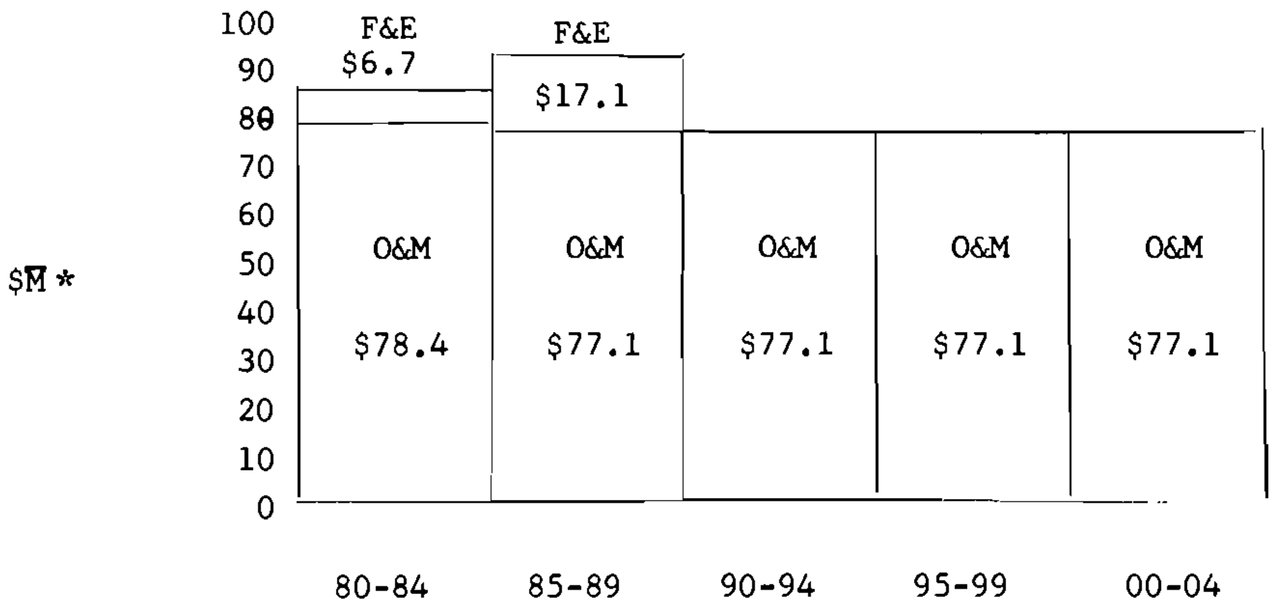
ILS	40	40	40	40	40	40

ARMY ACFT EQUIPMENTS PHASE OUT -- PHASE IN

SCENARIO B - NO MLS

CHART 2-14

ARMY
O&M/F&E COSTS
1980-2005
SCENARIO B - NO MLS



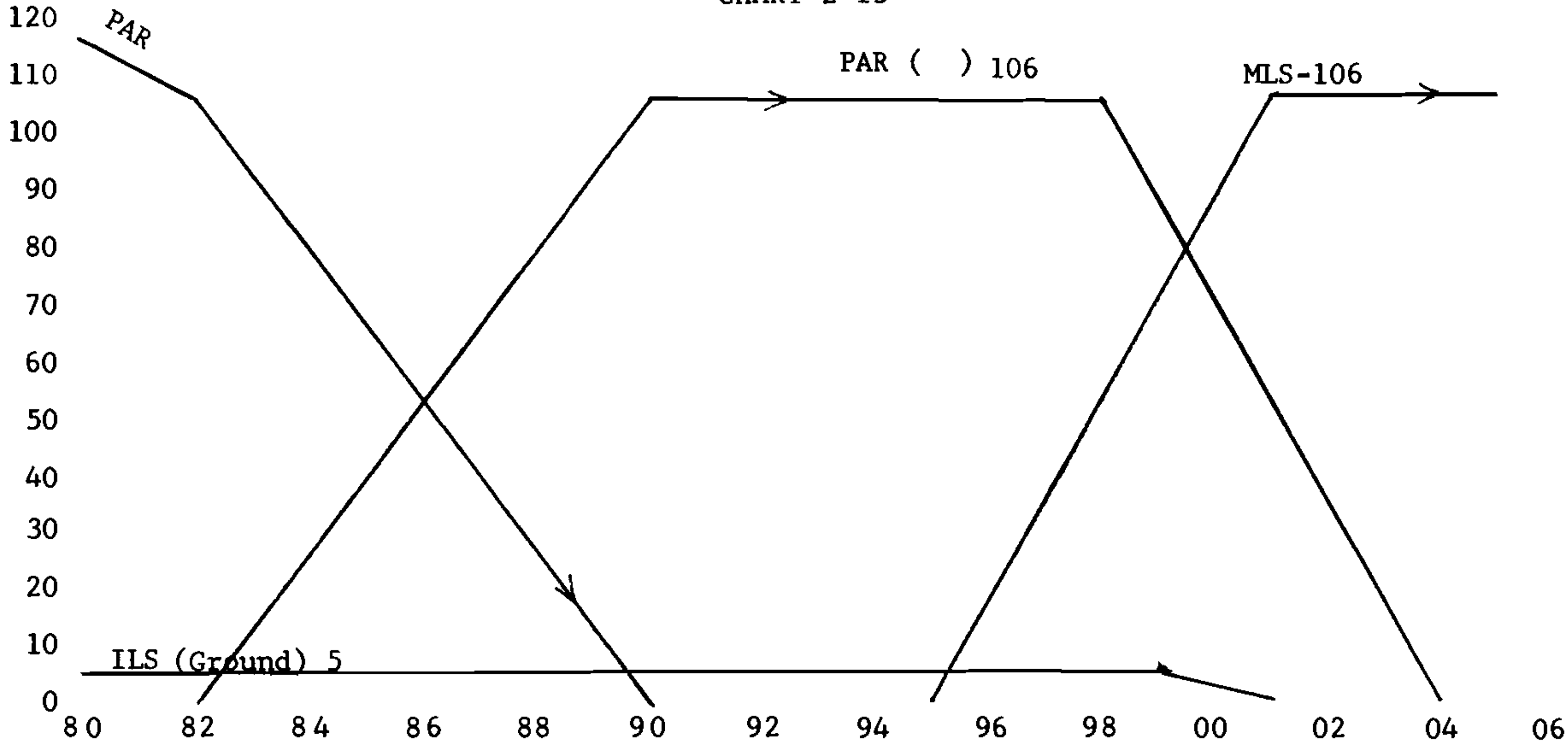
* Divide by 5 for average annual cost

ARMY EQUIPMENTS PHASE OUT - PHASE IN

SCENARIO C - MLS DELAYED FIVE YEARS

In Scenario C (MLS delayed five years), the Army would, as in the previous scenario, replace aging PARs with new PARs rather than adopt an interim microwave system. However, near the end of the Century, the MLS would begin to be phased in and PARs and ILS phased out. This scenario involves the highest total F&E costs while O&M costs remain high throughout the twenty-five year period.

CHART 2-15



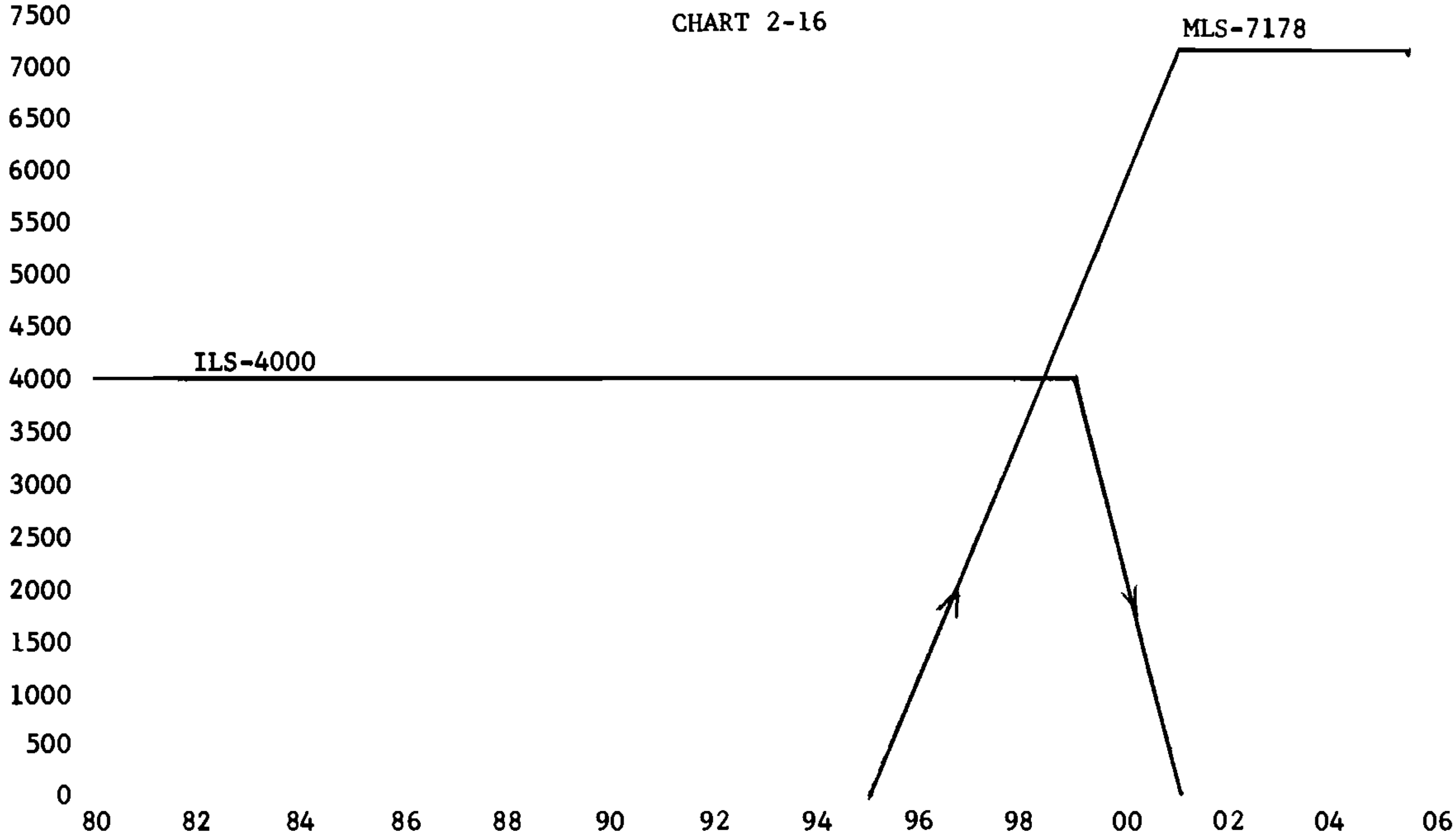
<u>Personnel</u>

PAR/ ILS	653	583	583	583	583	583	422	0
MLS	0	0	0	0	0	141	318	318

ARMY GROUND EQUIPMENTS PHASE OUT -- PHASE IN

SCENARIO C - MLS DELAYED 5 YEARS

CHART 2-16



<u>Personnel</u>

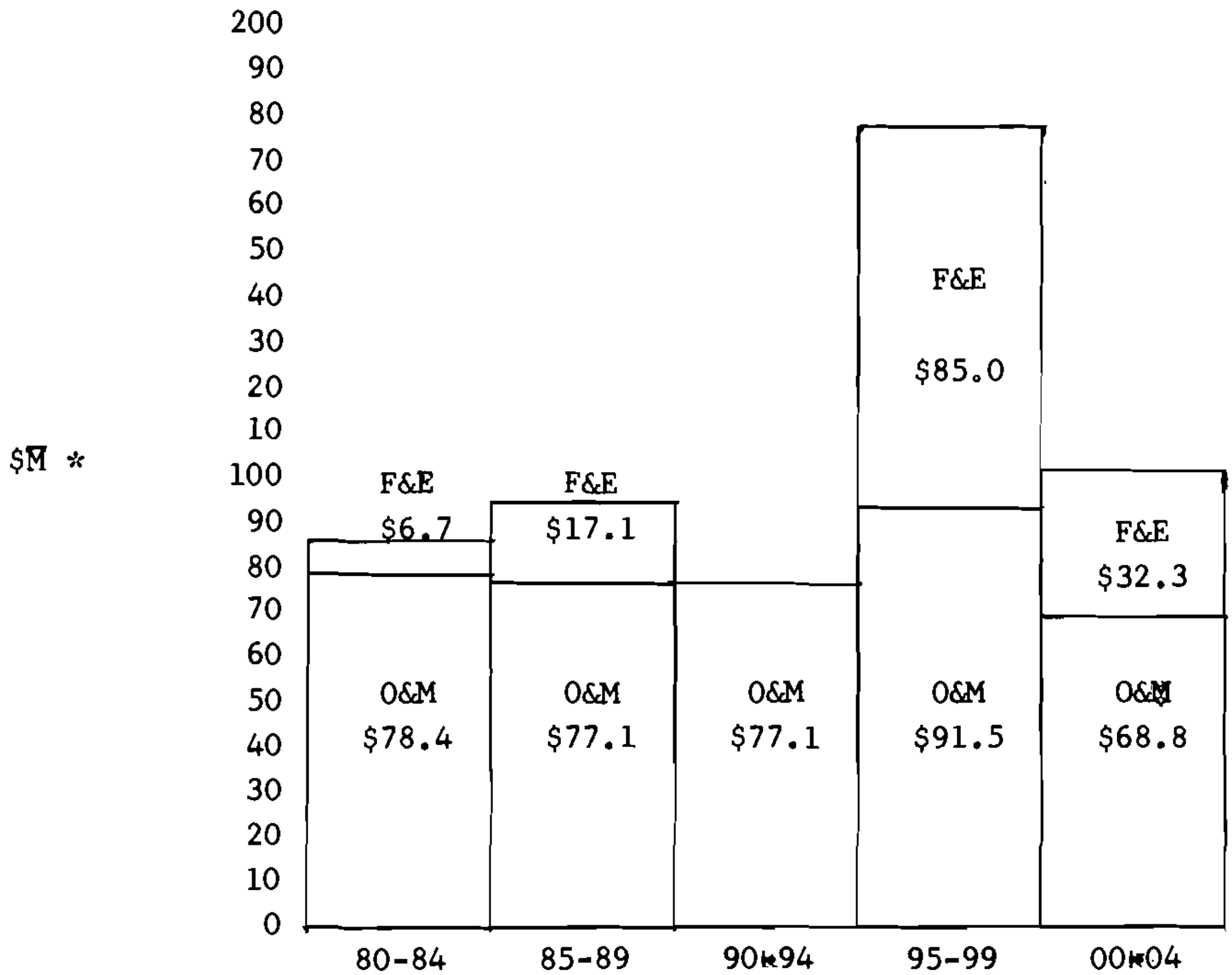
ILS	40	40	40	40	0	0
MLS	0	0	0	0	48	48

ARMY AIRCRAFT EQUIPMENTS PHASE OUT -- PHASE IN

SCENARIO C - MLS DELAYED 5 YEARS

CHART 2-17

ARMY
O&M/F&E COSTS
1980-2005
SCENARIO C
MLS DELAYED 5 YEARS



* Divide by 5 for average annual cost

NAVY/MARINE EQUIPMENTS PHASE OUT - PHASE IN

SCENARIO A - WITH MLS

Scenario A represents a partial acceptance of MLS by the Navy/Marine Corps. Until shipboard and tactical versions of MLS have been documented and proven as good or better than the recently installed and developing equipments such as SPN-41, SPN-42, MRAALS and TPN-22 full acceptance may not be expected.

Scenario A shows by the early 1980's Navy/Marine Corps have 59 shore locations all of which have solid state GCA equipments. These equipments are phased out and replaced by 95 MLS ground equipments. Eight TRN-28's and 4 ILS being used at shore stations also are phased out.

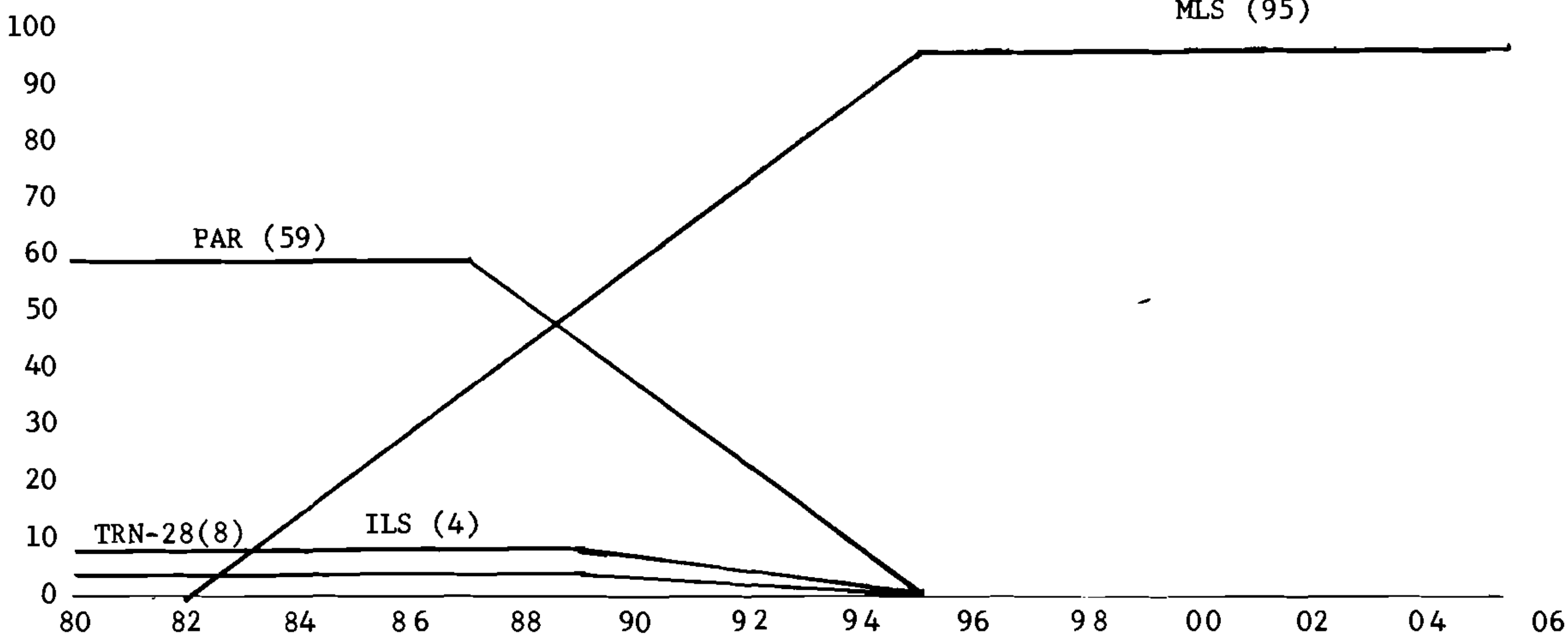
The Navy continues to use the SPN-42 aboard aircraft carriers as its primary landing system. The SPN-41 now used as a monitor for automatic landings is removed and replaced by MLS. The Marine Corps uses the TPN-22 as its primary landing system for expeditionary airfields. MLS replaces the two MRAALS equipments used at each site for monitoring automatic landings after 1997. Since MRAALS does not become operational until 1978 replacement by MLS is planned after 1995.

SPN-35 radars (GCA) continue as the primary landing system aboard LHA and LPD ships. TPN-8 is phased out as it is replaced by MRAALS.

Some of the aircraft (1244) retain a modified ARA-63 made compatible with MLS. The remainder have the new MLS installed - MLS retrofit problems were considered less in those aircraft where ARA-63 was removed than in those aircraft that had not had ARA-63 equipment.

Marine Corps helicopters are the last aircraft to receive MLS which follows the phase out of MRAALS in 1995 and replacement by MLS.

CHART 2-18



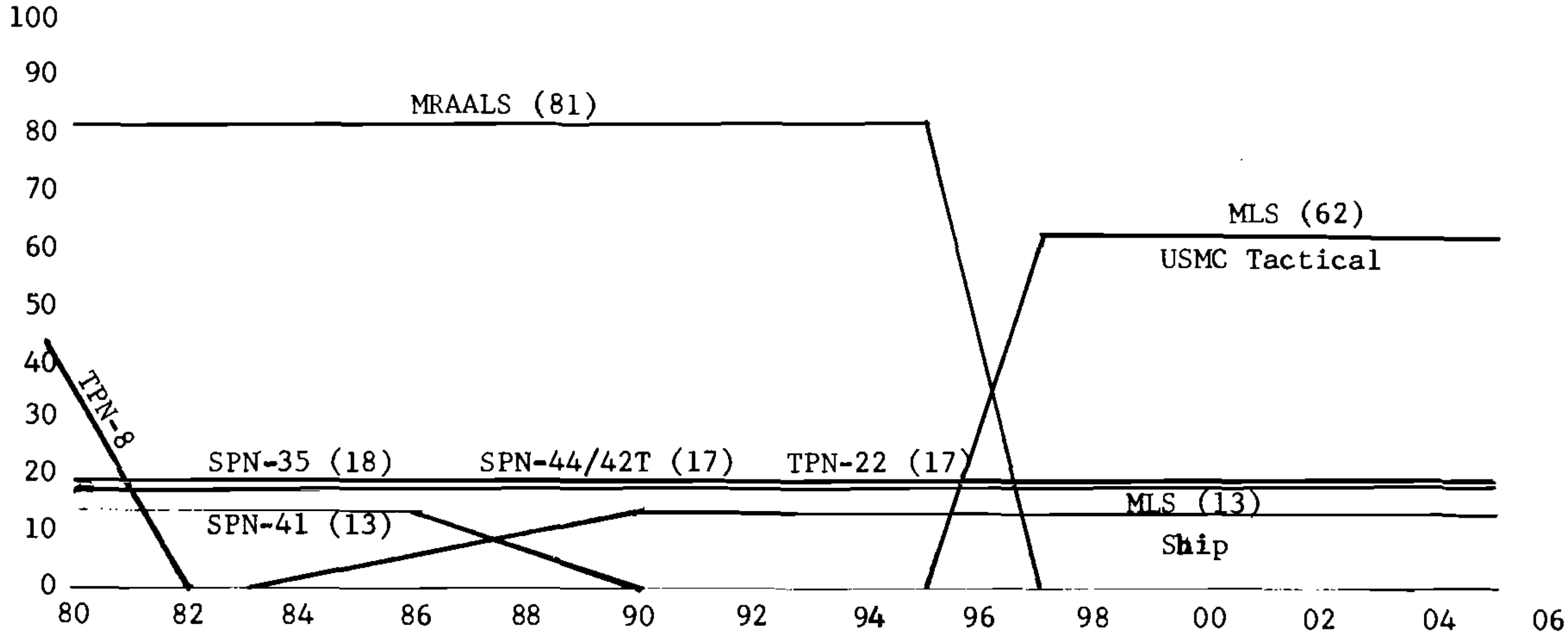
<u>Personnel</u>

PAR	590	590		590		590			390	220		0	0	0
ILS	12	12		12		12		12		6		0	0	0
MLS		0	45	66	87		129		174	219	261	285	285	285
TRN-28	24	24		24					24	12		0	0	0

NAVY/MARINE SHORE EQUIPMENTS PHASE OUT -- PHASE IN

SCENARIO A - WITH MLS

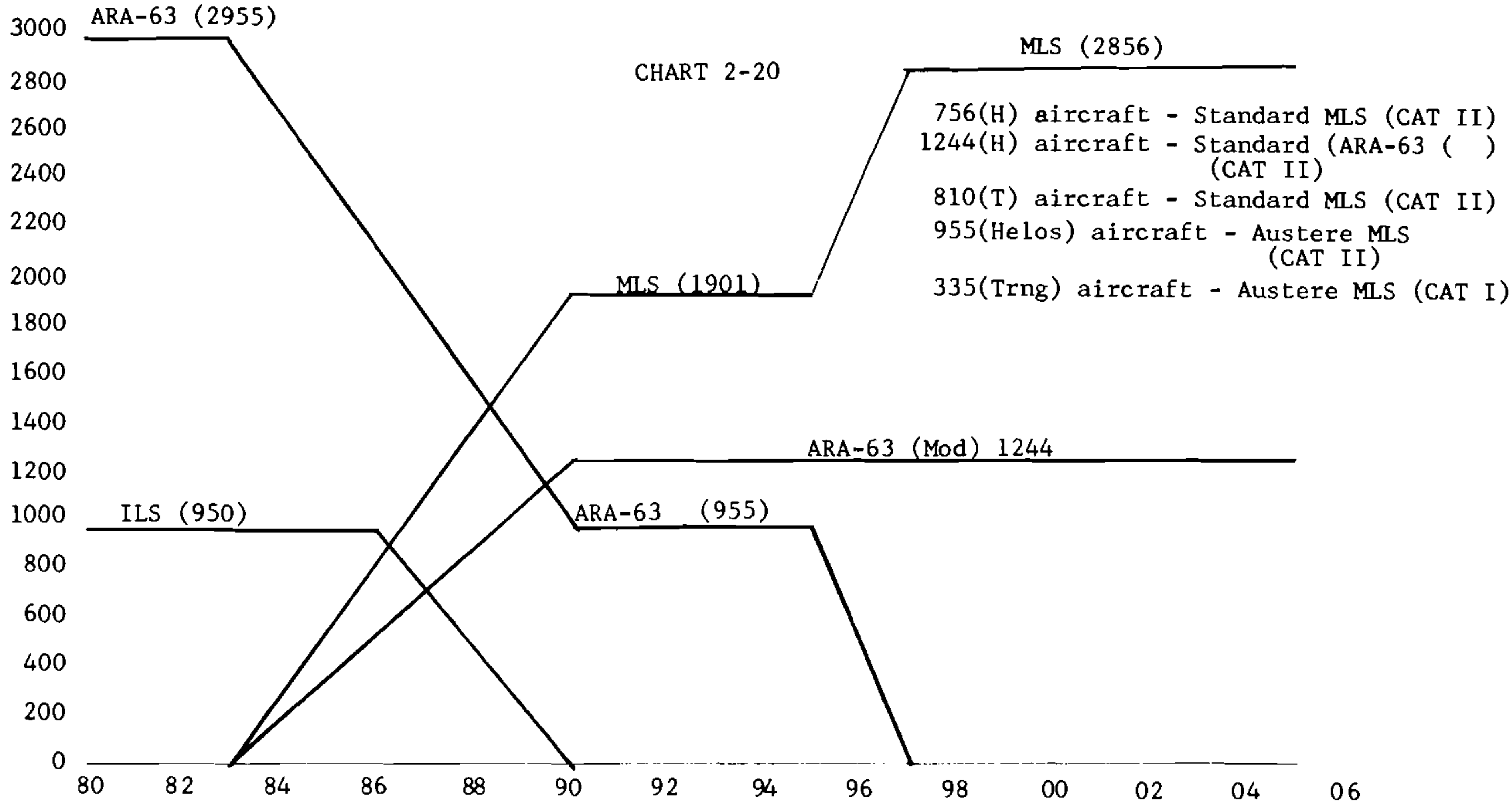
CHART 2-19



Personnel

TPN-22	170	170			170		170			170	170	170
SPN-42/ 42T	170	170			170		170			170	170	170
TPN-8	237	0										
SPN-35	99	99			99		99			99	99	99
SPN-41	4	4	4	4	3	0					0	0
MRAALS	192	192			192		192	192	95	0	0	0
MLS			0		2	4	4	4	100	190	190	190

NAVY/MARINE TACTICAL EQUIPMENTS PHASE OUT -- PHASE IN
SCENARIO A - WITH MLS

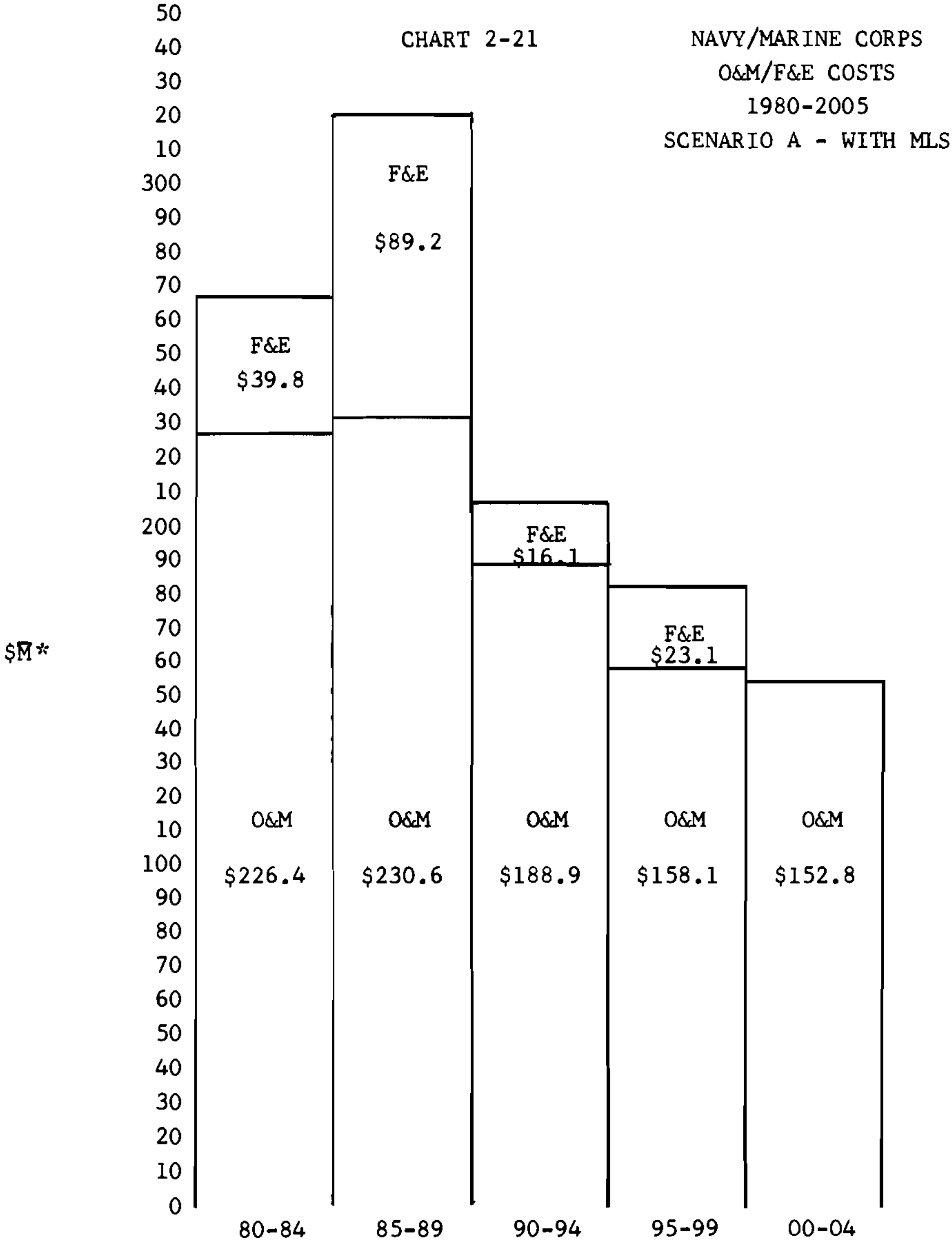


<u>Personnel</u>

ARA-63	30	30		15	10	10	0	0	0
ILS	10	10	10	5	0	0		0	0
ARA-63(Mod)		0		9	13	13		13	13
MLS		0		14	19	19	29	29	29

NAVY/MARINE ACFT EQUIPMENTS

SCENARIO A - WITH MLS



* Divide by 5 for average annual cost

NAVY/MARINE CORPS EQUIPMENTS PHASE OUT - PHASE IN

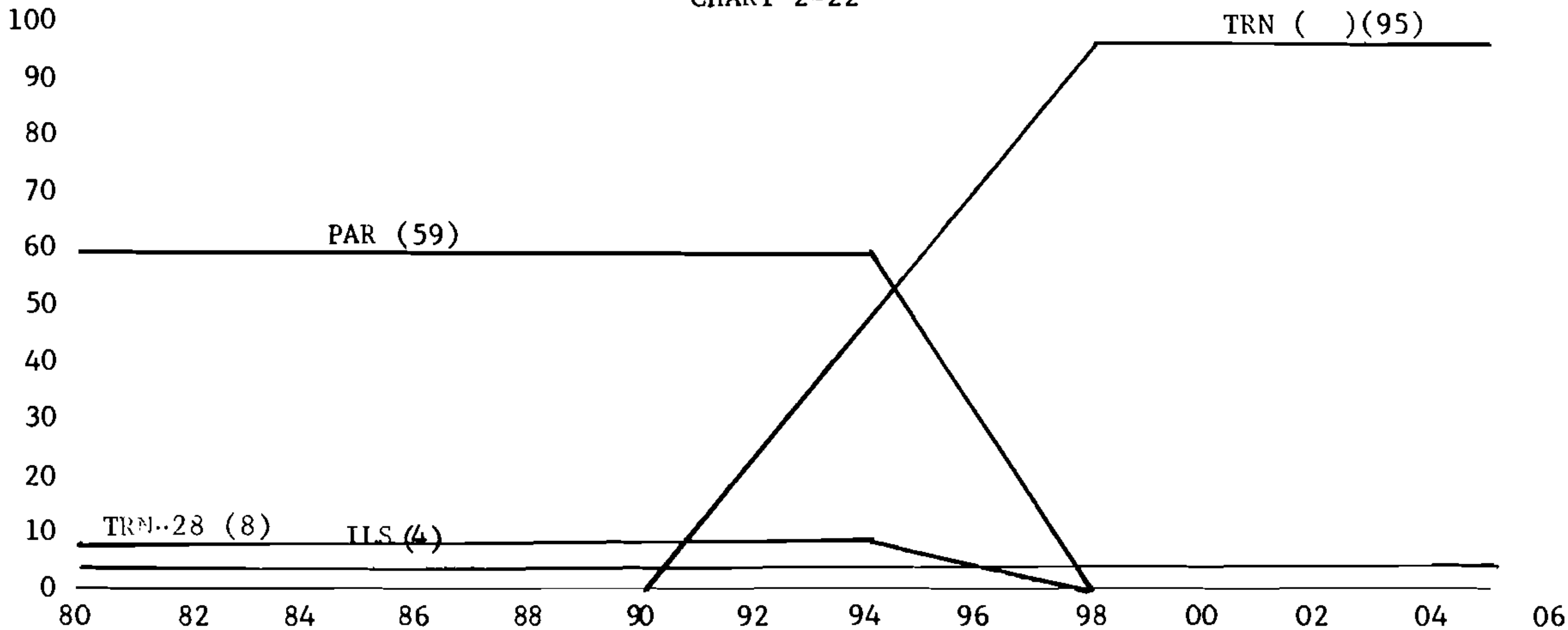
SCENARIO B - NO MLS

The Navy/Marine Corps have implemented or have in production several new landing systems which meet their needs but they lack interoperability with other services and civil aviation. These equipments could be used as depicted in Scenario B charts that follow.

The Solid State PAR's are used for shore stations until the 1990's and then replaced with some version (TRN ( )) of the already developed scanning beam MLS equipments such as the SPN-41/TRN-28 or MRAALS. All Navy/Marine Corps aircraft would have the same avionics, ARA-63. Equipment installation and O&M costs for TRN ( ) is the same as for MLS Standard (Fixed) ground equipment.

The SPN-42 is used aboard aircraft carriers and the TPN-22 for Marine Corps expeditionary use. Avionics for both the SPN-42 and TPN-22 systems are the same. Initial operational capability for TPN-22 may be about 1979. MRAALS may become operational about 1978 and could continue to meet Marine tactical needs for many years.

CHART 2-22



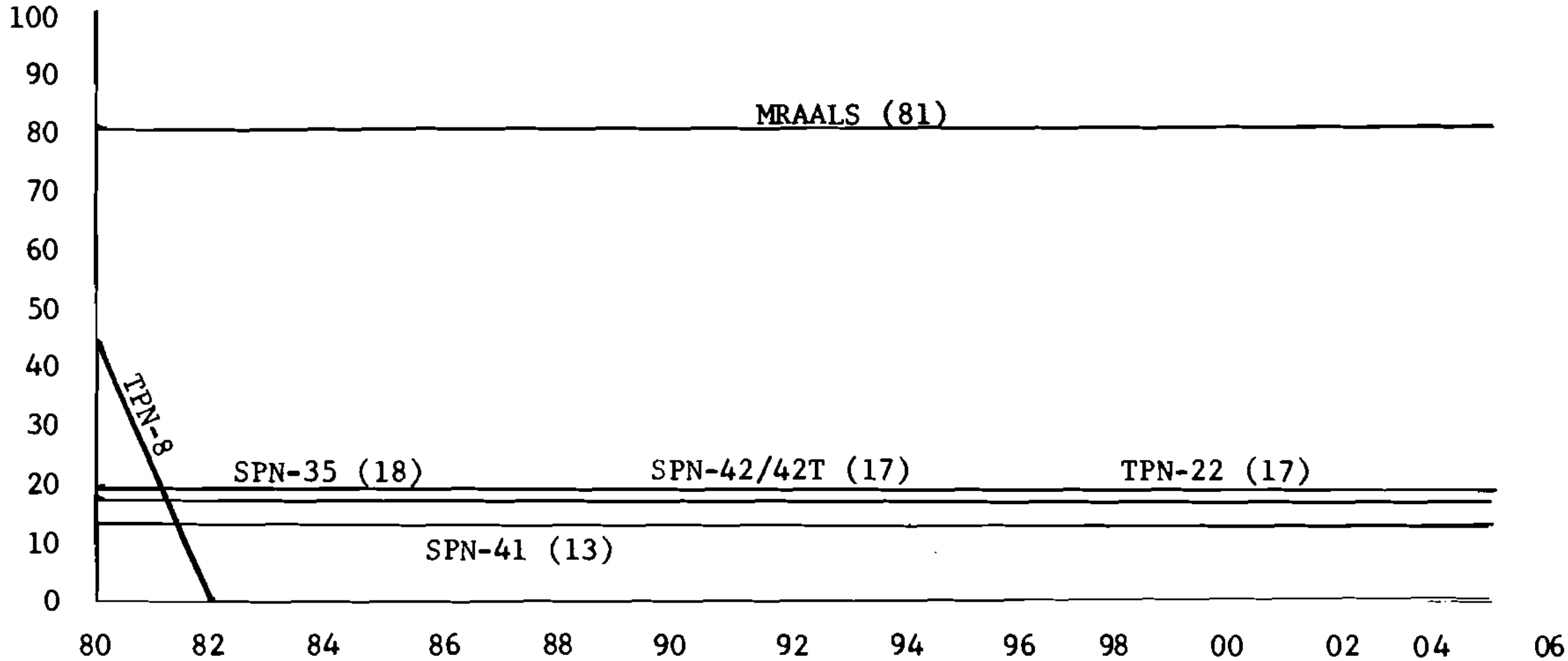
Personnel

PAR	590	590	590	590		590	450		0	0	0
ILS	12	12	12	12		12	12			12	12
MLS				0	72		177		285	285	285
TRN-28	24	24	24	24		24		12	0	0	0

NAVY/MARINE SHORE EQUIPMENTS PHASE OUT -- PHASE IN

SCENARIO B - NO MLS

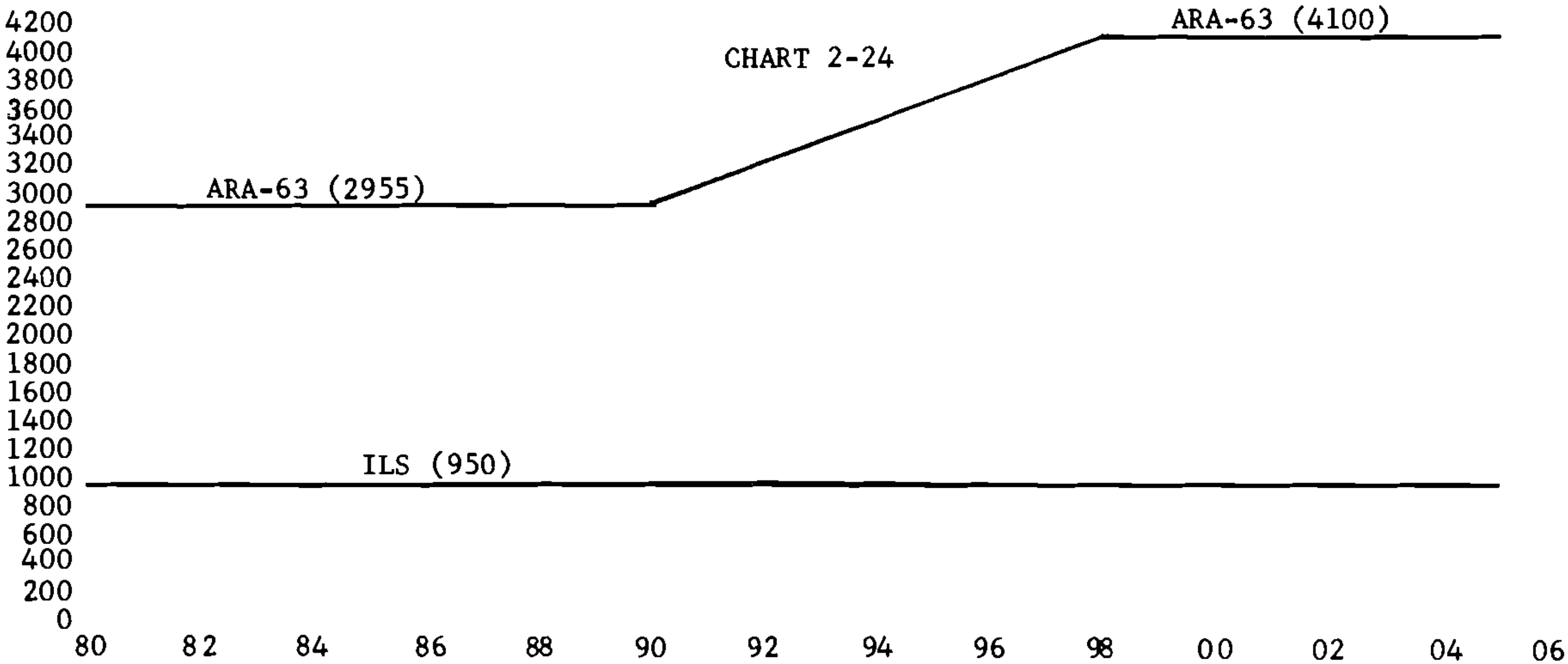
CHART 2-23



Personnel

TPN-22	170	170	170	170	170	170	170
SPN-42/ 42T	170	170	170	170	170	170	170
TPN-8	237	0		0	0	0	0
SPN-35	99	99	99	99	99	99	99
SPN-41	4	4	4	4	4	4	4
MRAALS	192	192	192	192	192	192	192

NAVY/MARINE TACTICAL EQUIPMENTS PHASE OUT -- PHASE IN
SCENARIO B - NO MLS



<u>Personnel</u>

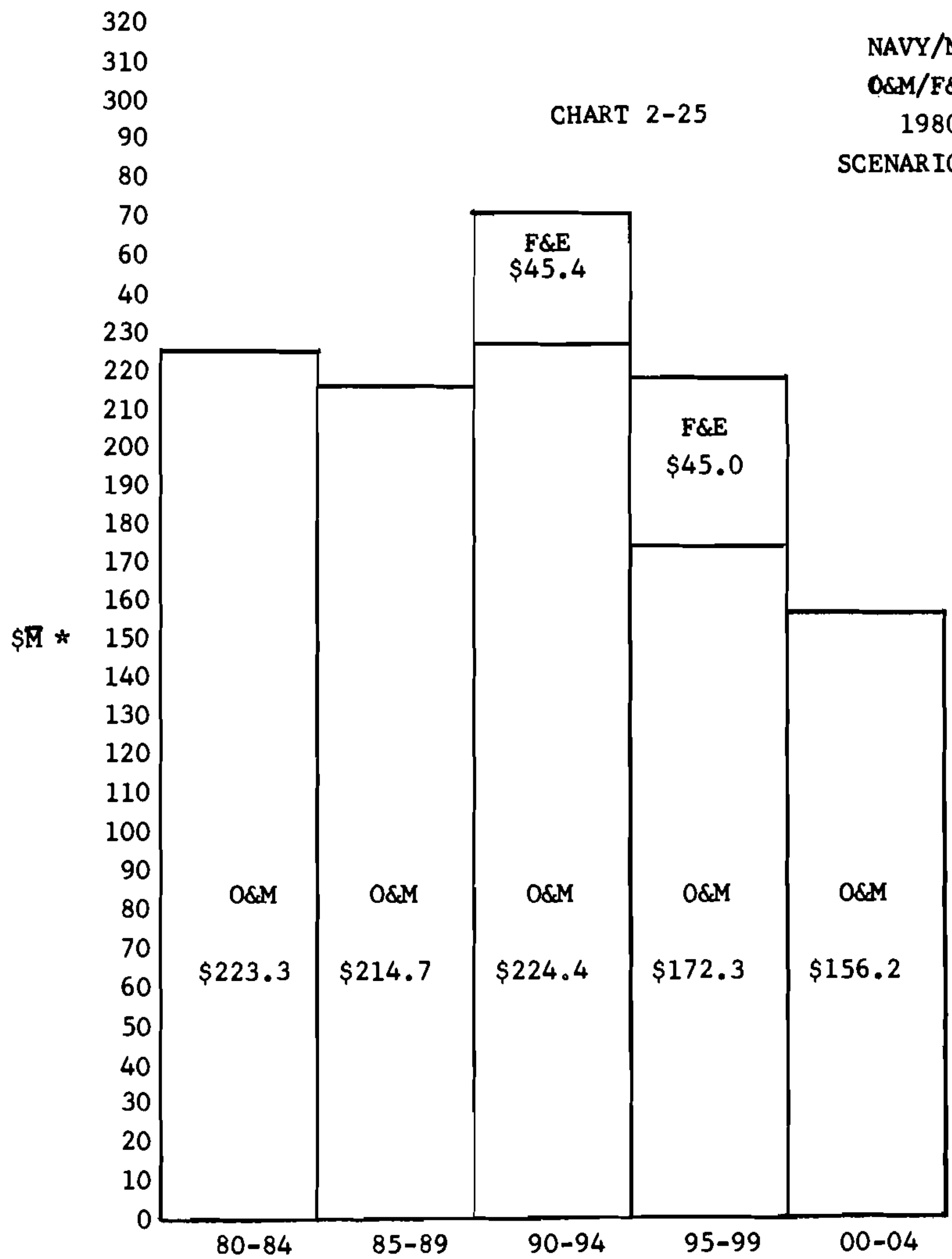
ARA-63	30	30	30	30	38	41	41
ILS	10	10	10	10	10	10	10

NAVY/MARINE ACFT EQUIPMENTS

SCENARIO B - NO MLS

CHART 2-25

NAVY/MARINE CORPS
O&M/F&E COSTS
1980-2005
SCENARIO B - NO MLS



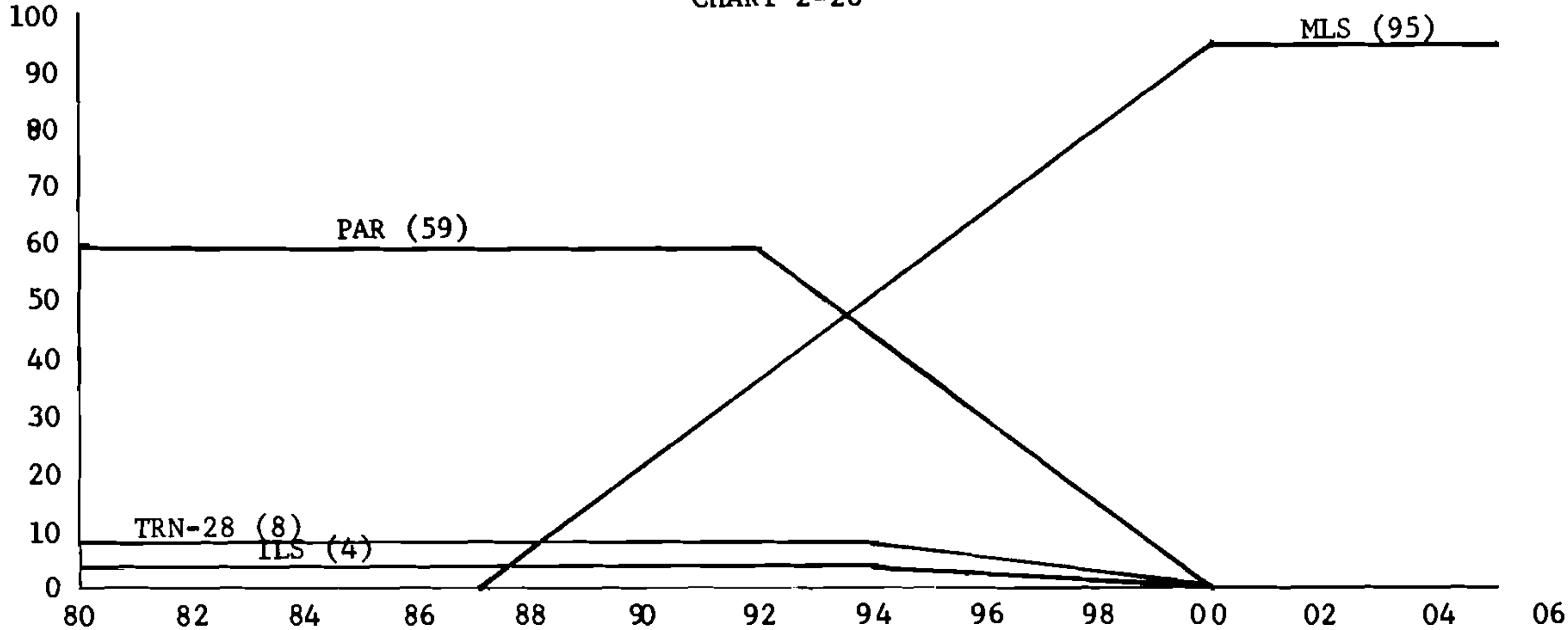
* Divide by 5 for average annual cost

NAVY/MARINE CORPS EQUIPMENTS PHASE OUT - PHASE IN

SCENARIO C - WITH MLS DELAYED 5 YEARS

This scenario is similar to Scenario A except MLS availability is delayed five years. MLS implementation for shore and ship use would be five years later than Scenario A. MLS implementation for Marine Corps tactical needs would be the same as in Scenario A and starting in 1995.

CHART 2-26

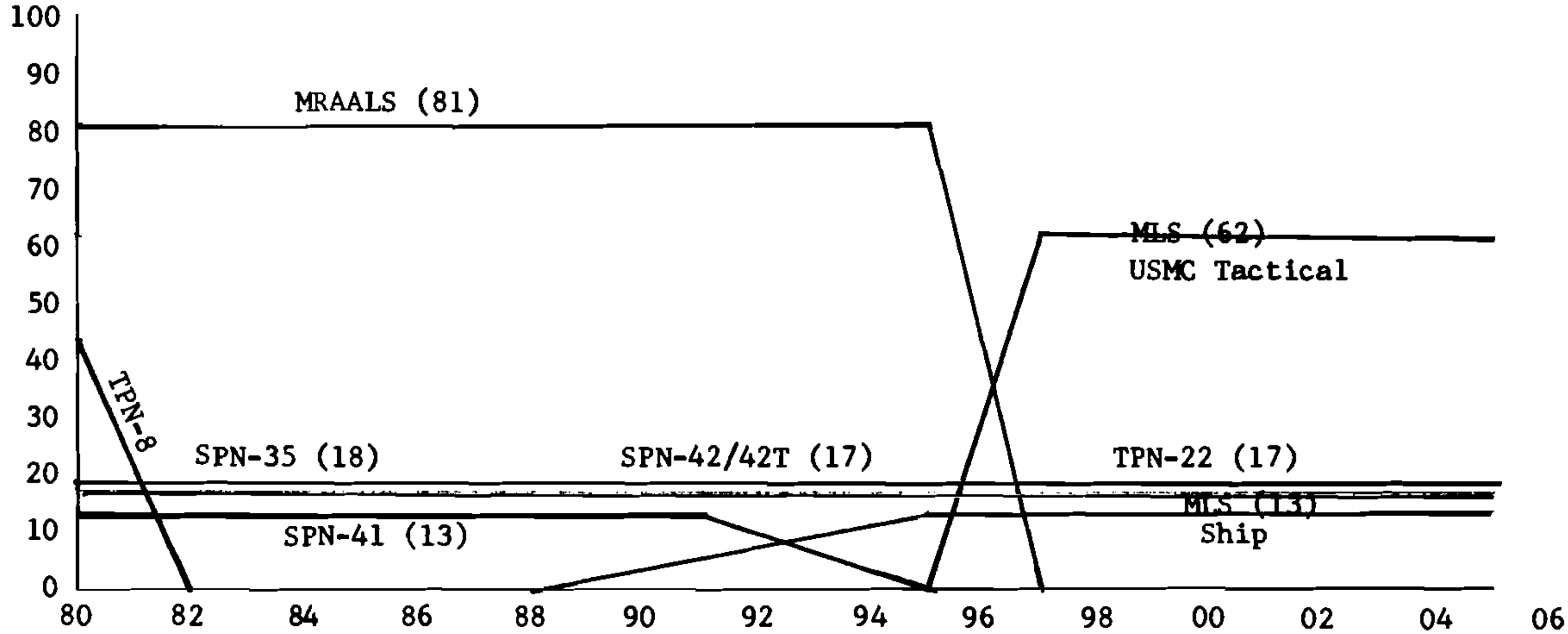


Personnel

PAR	590	590	590	590	590		360	0	0
ILS	12	12	12	12	12		9	0	0
MLS			0	66			174	285	285
TRN-28	24	24	24	24		24	21	0	0

NAVY/MARINE SHORE EQUIPMENTS PHASE OUT -- PHASE IN
SCENARIO C - WITH MLS delayed 5 years

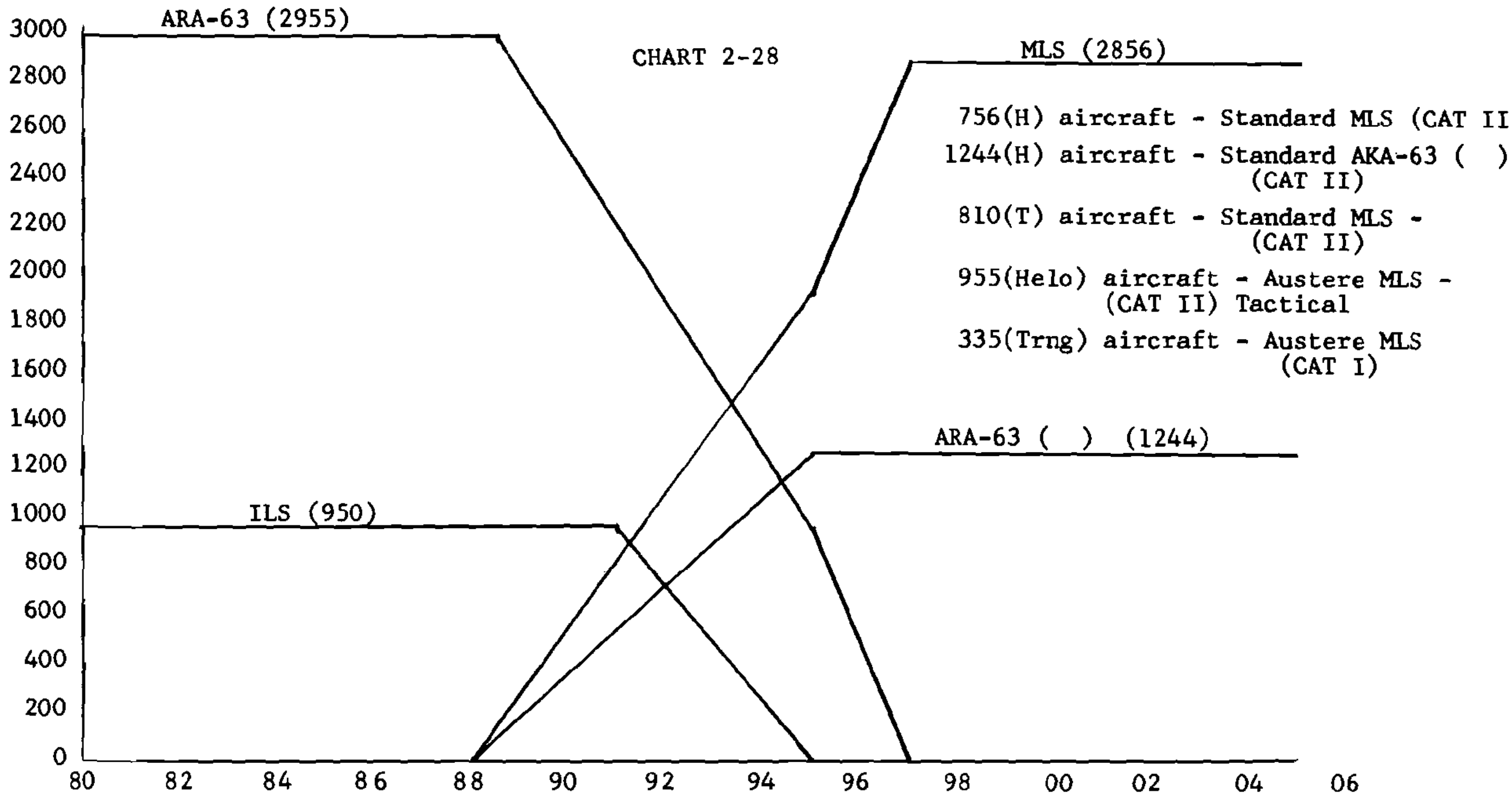
CHART 2-27



Personnel

TPN-8	237	0									0
SPN-35	99		99		99		99			99	99
SPN-41	4		4		4	4	0			0	0
MRAALS	192		192		192		192	95	0	0	0
SPN-42/ 42T	170		170		170		170			170	170
TPN-22	170		170		170		170			170	170
MLS				0	2		4	100	190	190	190

NAVY/MARINE TACTICAL EQUIPMENTS PHASE OUT -- PHASE IN
SCENARIO C - WITH MLS DELAYED 5 YEARS



<u>Personnel</u>

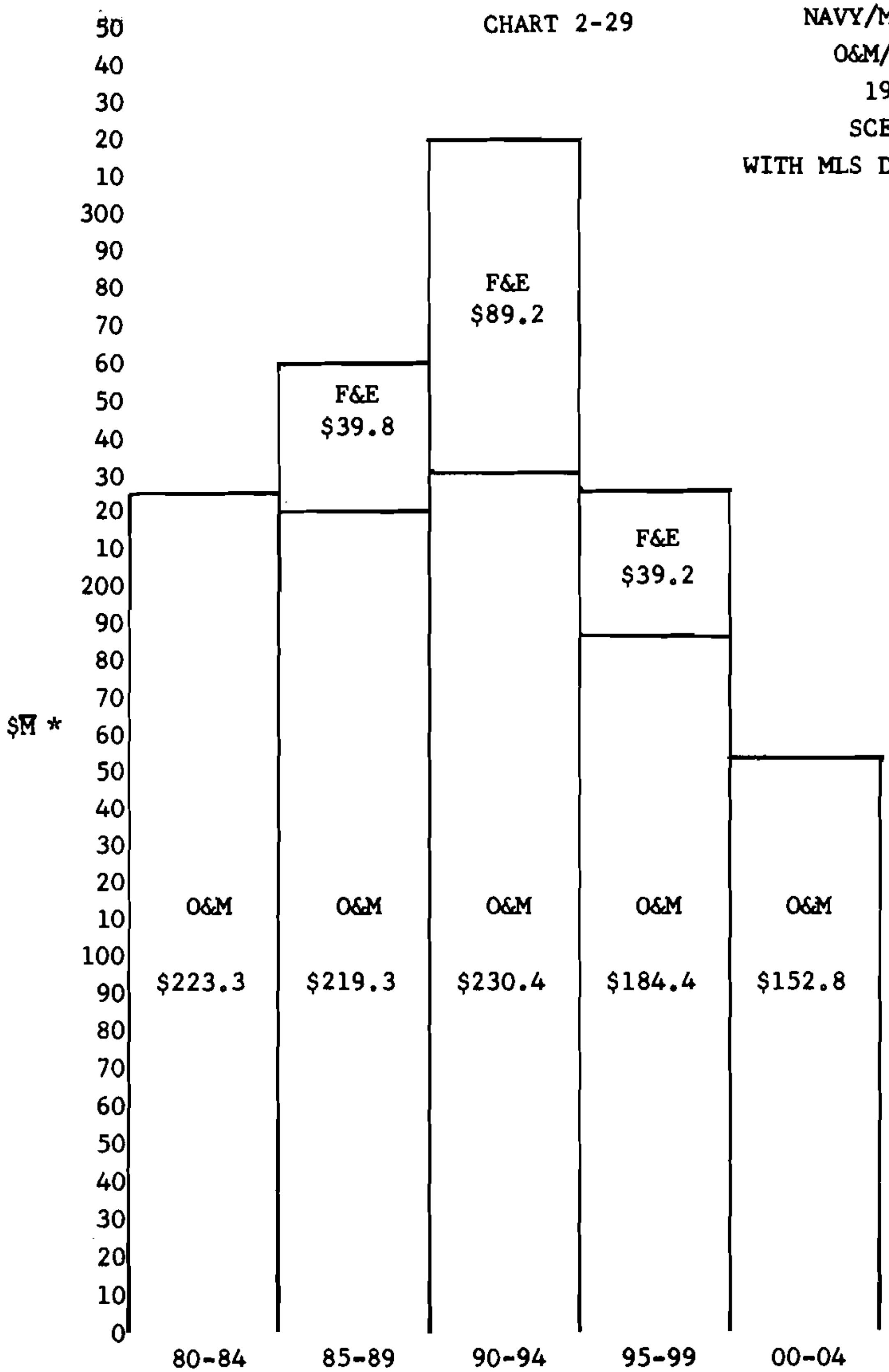
ARA-63	30	30	30		24		15	10	0	0	0
ILS	10	10	10	10	10	10	5	0	0	0	0
ARA-63 (Mod)			0				9	13	13	13	13
MLS			0		6		14	19	29	29	29

NAVY/MARINE ACFT EQUIPMENTS

SCENARIO C - WITH MLS DELAYED 5 YEARS

CHART 2-29

NAVY/MARINE CORPS
O&M/F&E COSTS
1980-2005
SCENARIO C
WITH MLS DELAYED 5 YEARS



* Divide by 5 for average annual cost

NAVY/MARINE EQUIPMENTS PHASE OUT - PHASE IN

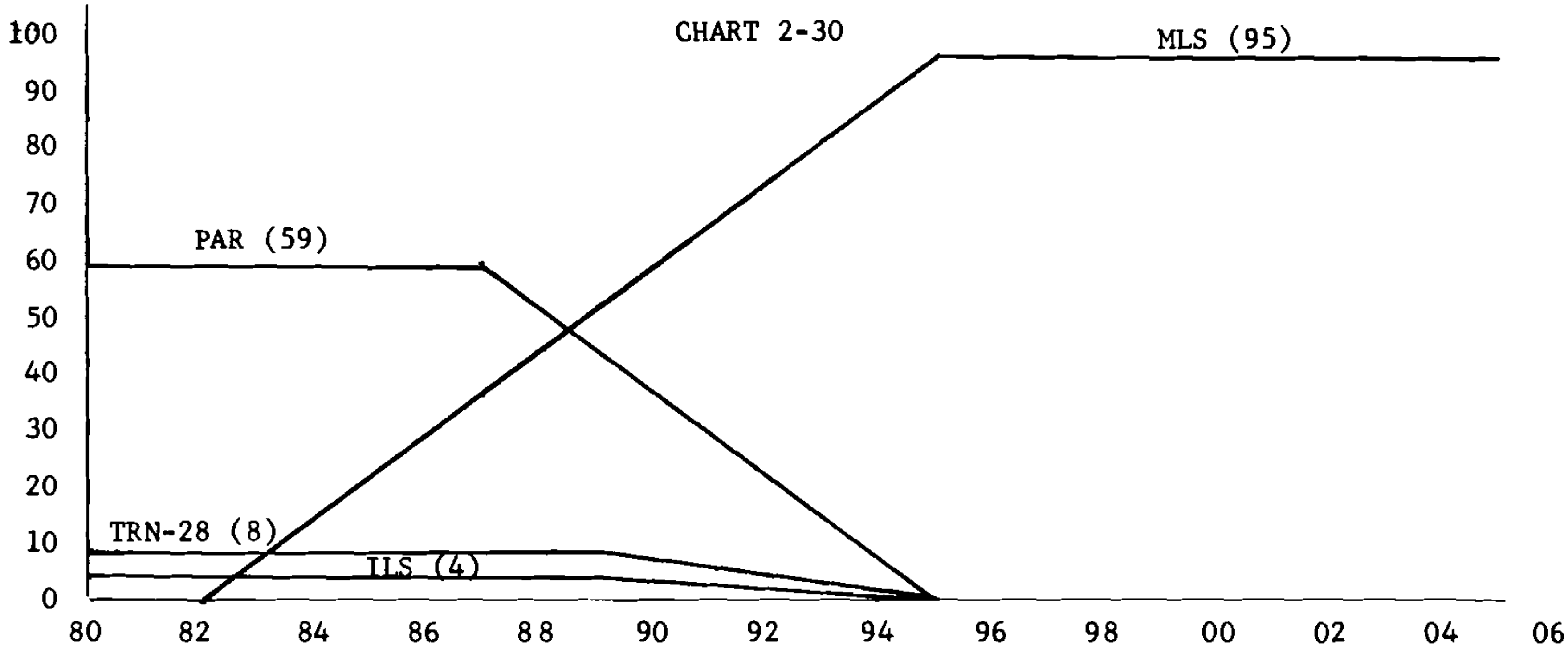
SCENARIO D - MLS PRIMARY LANDING SYSTEM

Scenario D represents a possible plan where Navy/Marine Corps have seen the MLS demonstrated and are convinced that it would perform as well and possibly better than any of their existing and developing equipments. Performance, commonality and O&M cost benefits could require the change to MLS as primary landing system.

Replacement of PARs with MLS at shore stations is the same as in Scenario A.

Aboard ship MLS replaces SPN-42. SPN-41 is retained for monitoring and possibly may be modified to give a GCA presentation for Carrier Air Traffic Control Personnel (CATCC). Similarly TPN-22 is replaced by MLS and two MRAALS are retained for monitoring at each expeditionary site. SPN-35 is replaced by MLS aboard the smaller ships (LHA, LPD).

All aircraft have MLS avionics. Navy and Marine Corps high performance aircraft also retain ARA-63.

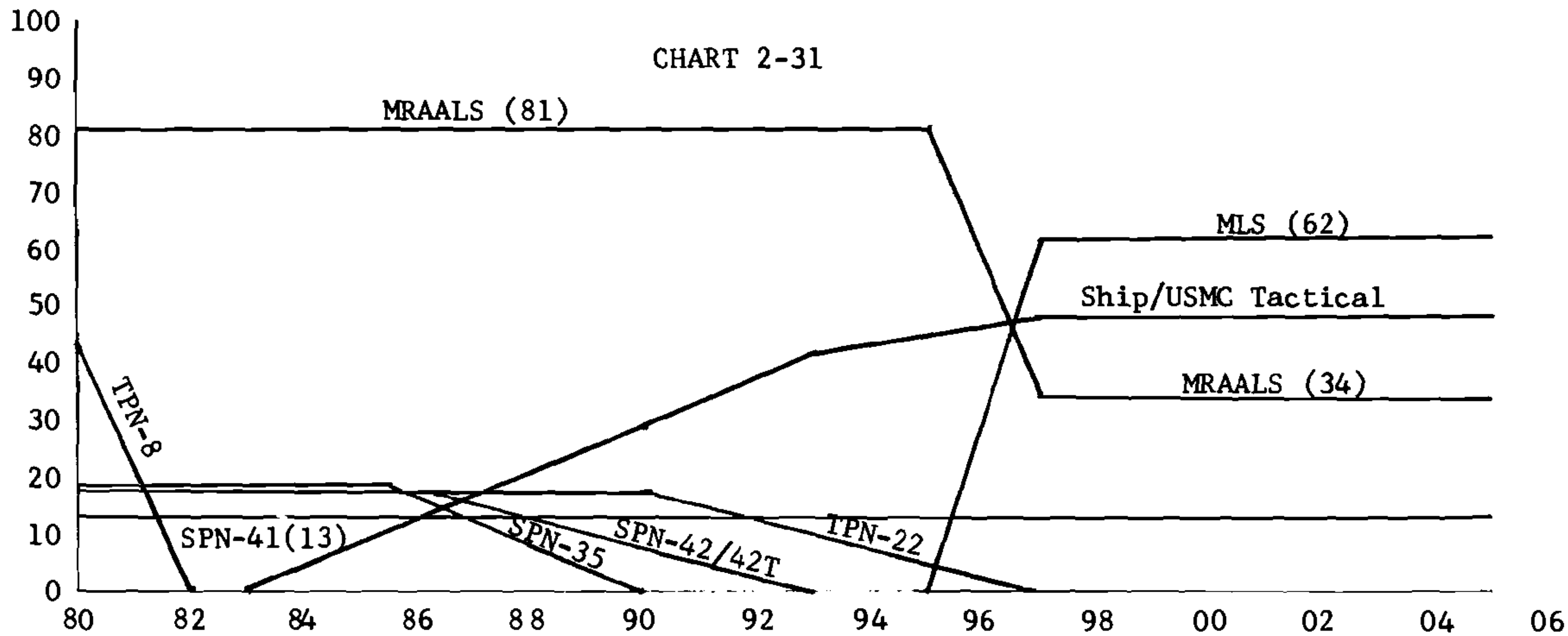


Personnel

PAR	590	590		590		590			390	220		0	0	0
ILS	12	12		12		12		12		6		0	0	0
MLS		0	45	66	87		129		174	219	261	285	285	285
TRN-28	24	24		24				24		12		0		0

NAVY/MARINE SHORE EQUIPMENTS PHASE OUT -- PHASE IN

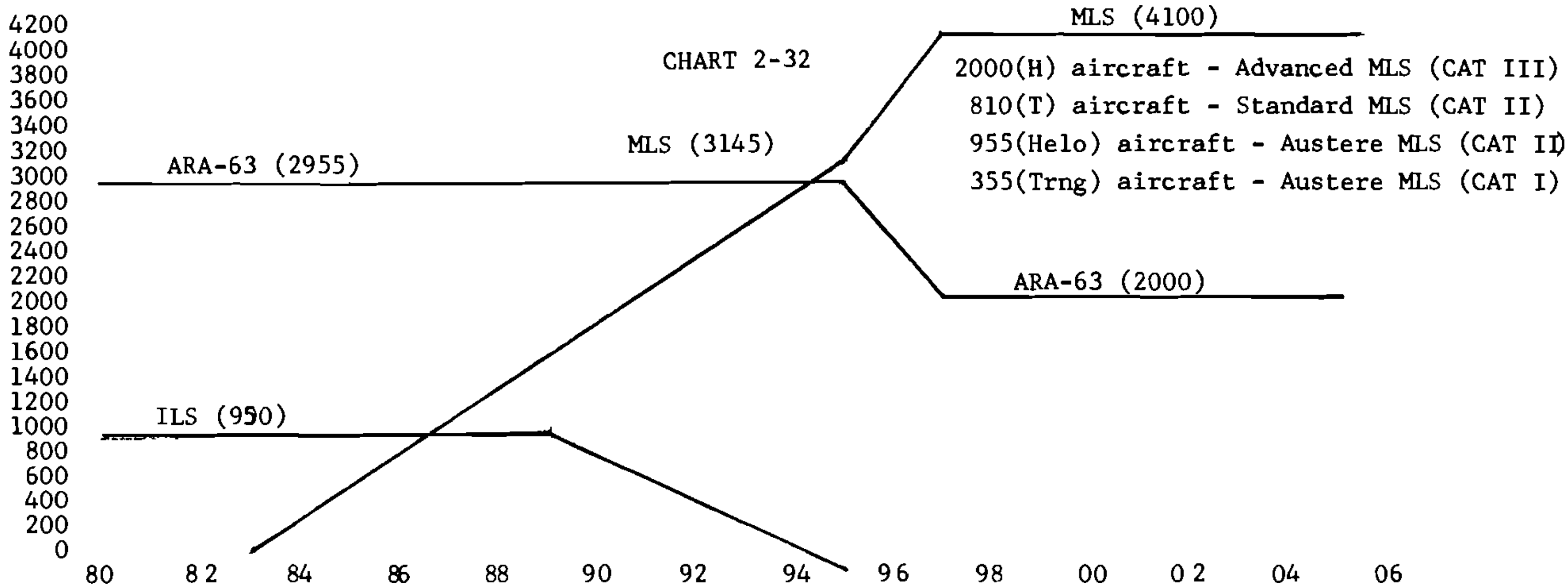
SCENARIO D - MLS PRIMARY LANDING SYSTEM



Personnel

TPN-22	170	170		170			170	120		50		0	0	0
TPN-8	237	0		0			0			0			0	0
SPN-35	99	99		99		39	0			0			0	0
SPN-41	4	4		4		4	4			4			4	4
MRAALS	192	192		192		192	192			192	95	51	51	51
SPN-42/ 42T	170	170		170	170		70			0			0	0
MLS			0		21		63		99	123		330	330	330

NAVY/MARINE TACTICAL EQUIPMENTS PHASE OUT -- PHASE IN
SCENARIO D, MLS PRIMARY LANDING SYSTEM



<u>Personnel</u>

ARA-63	30	30		30	30	30	30	20	20	20
ILS	10		10	10	5	0			0	0
MLS	0			23		52	52	59	59	59

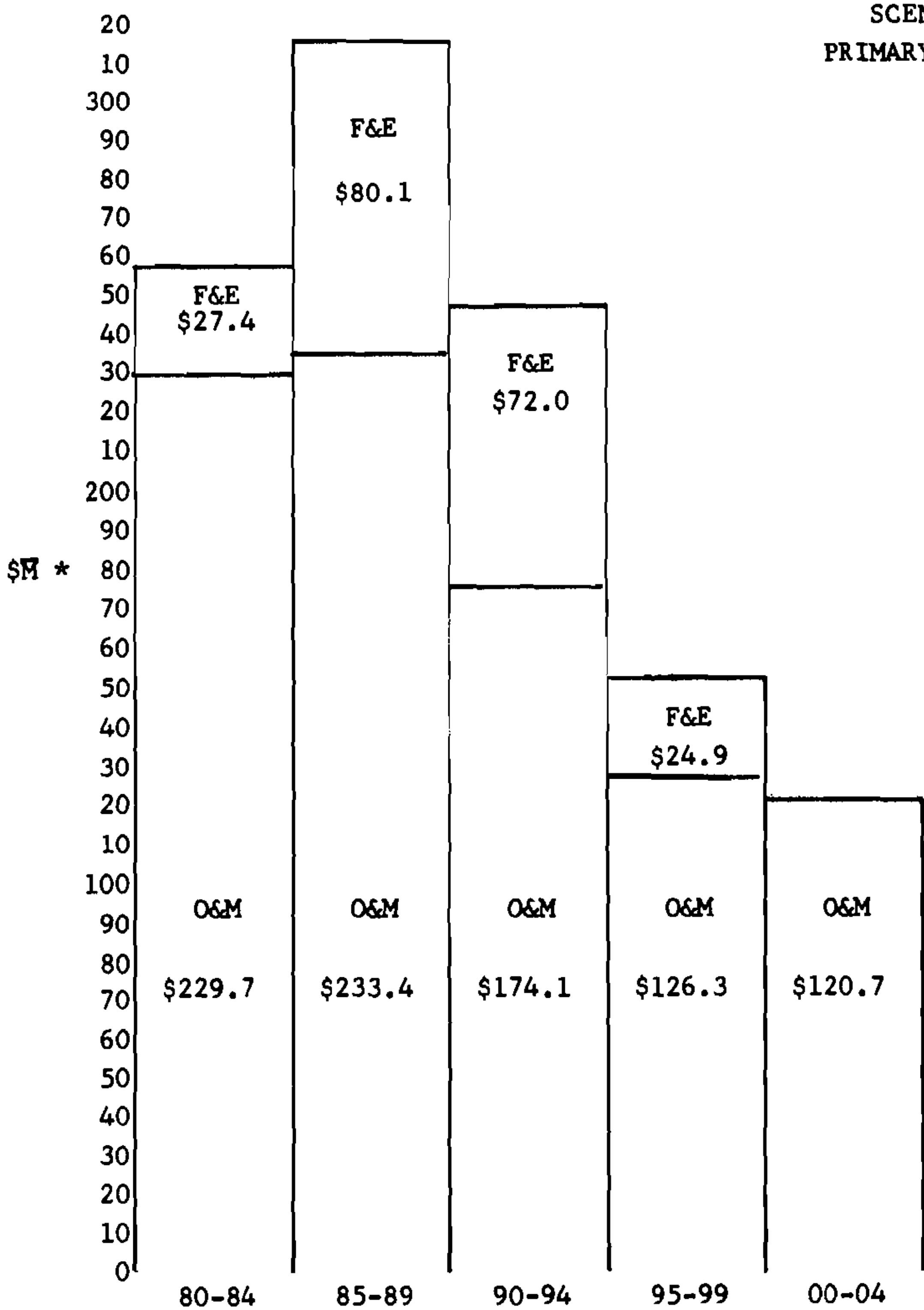
NAVY/MARINE ACFT EQUIPMENTS

SCENARIO D

MLS PRIMARY LANDING SYSTEM

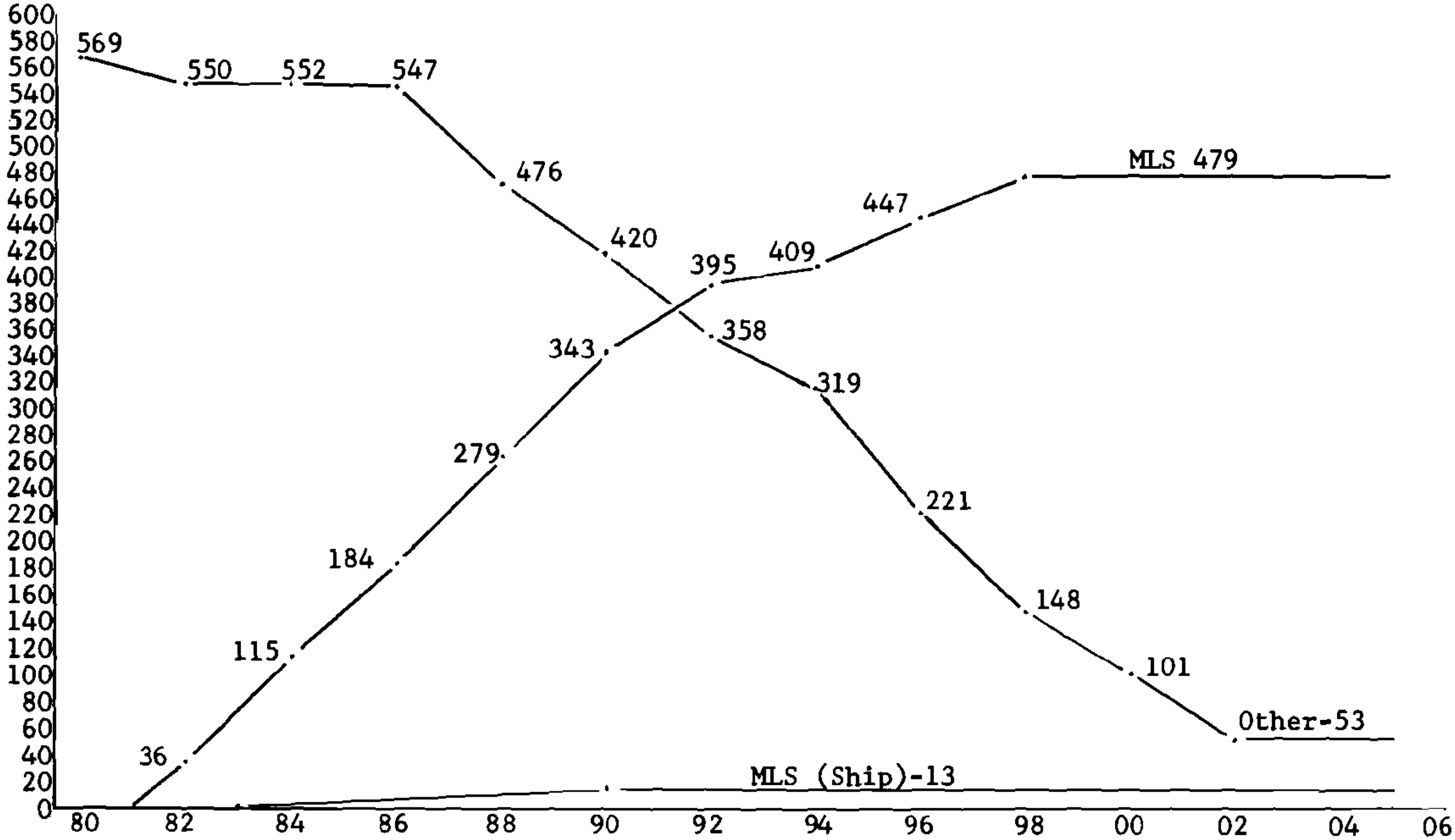
NAVY/MARINE CORPS
O&M/F&E COSTS
1980-2005
SCENARIO D - MLS
PRIMARY LANDING SYSTEM

CHART 2-33



* Divide by 5 for average annual cost

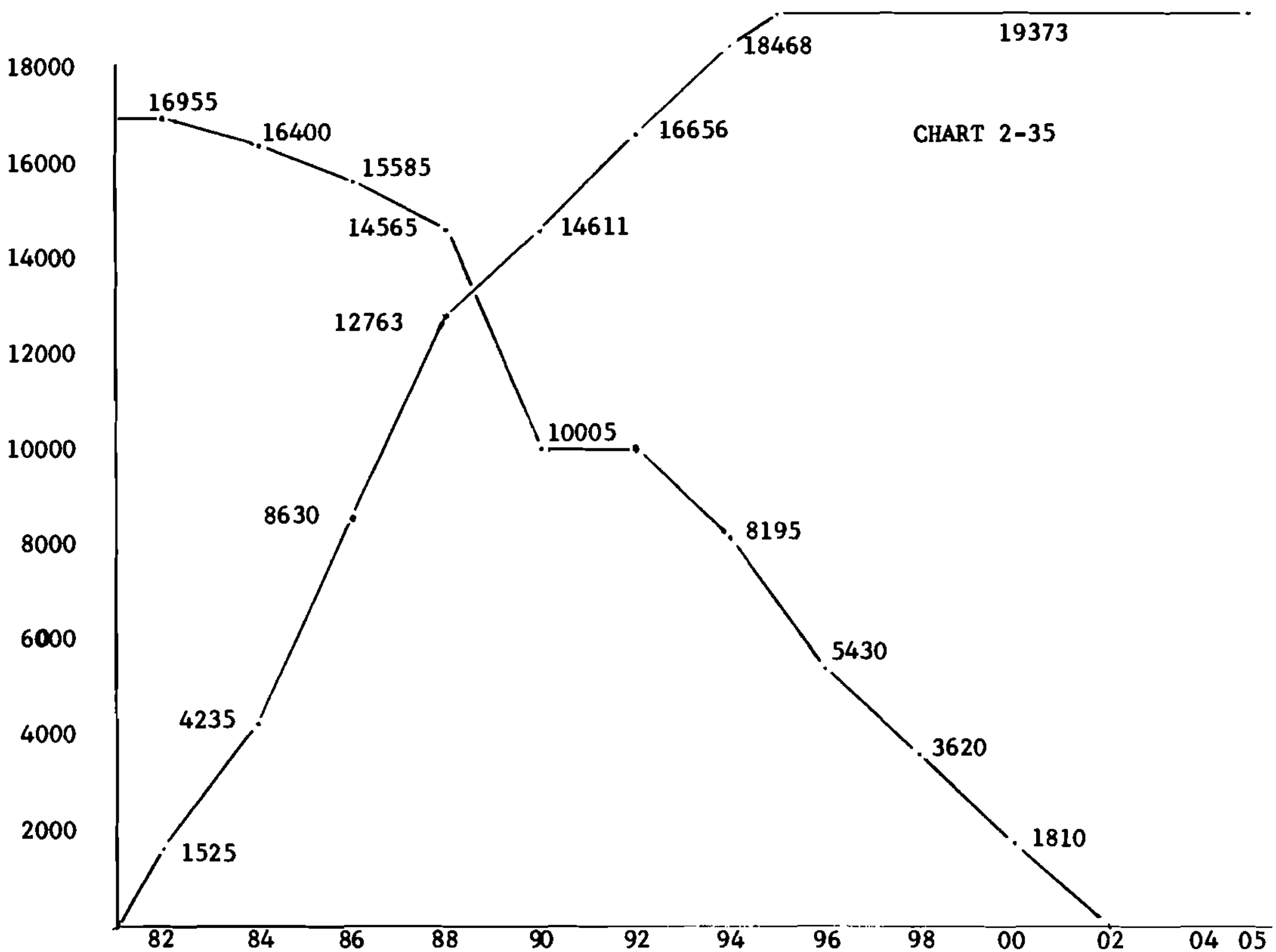
CHART 2-34



Personnel		
MLS	0	1441
Other	3215	439
Total	3215	1880

MILITARY COMBINED SURFACE
EQUIPMENT PHASE OUT - PHASE IN

SCENARIO A - WITH MLS



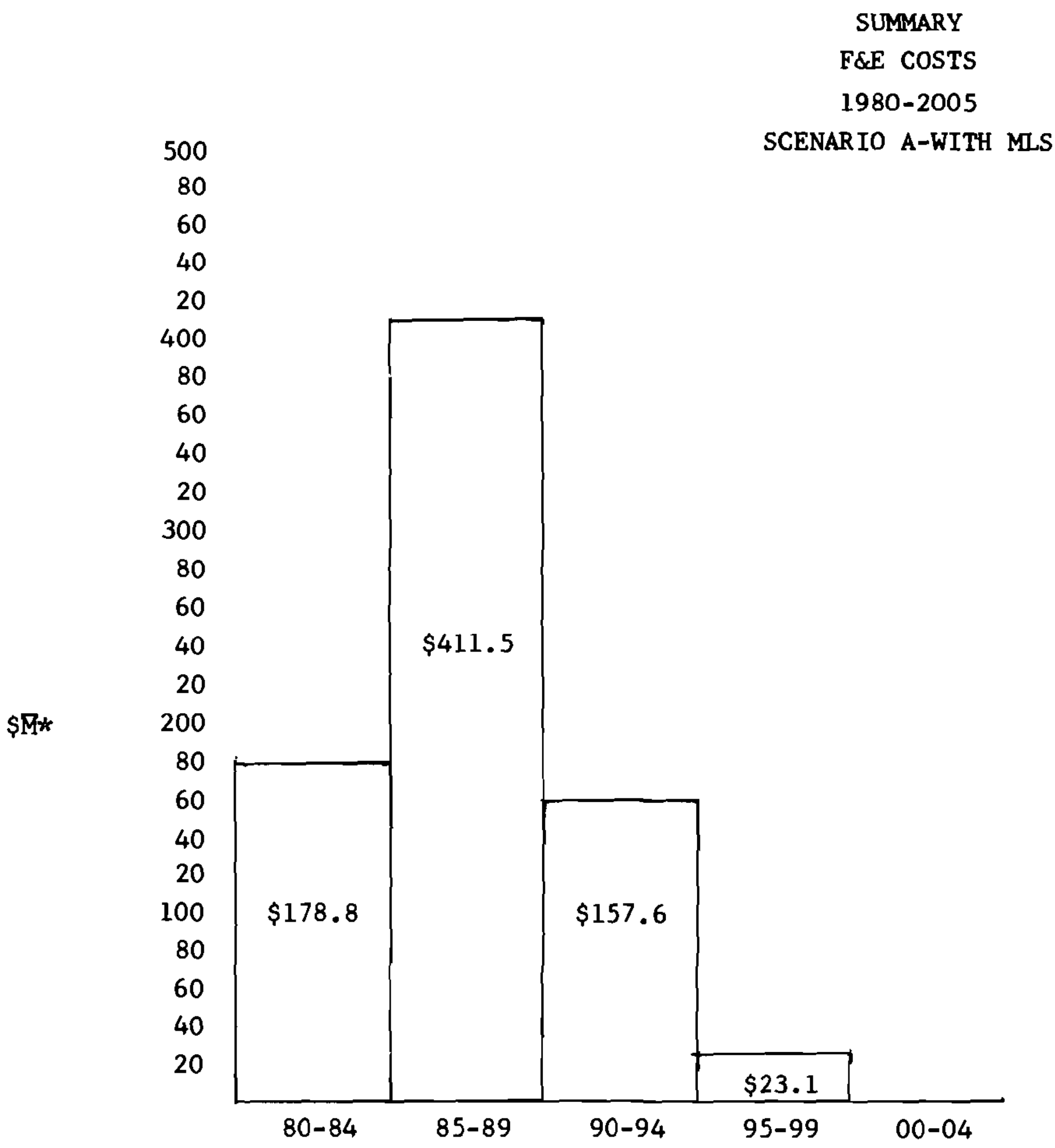
Personnel	82	05
MLS	3	180
Other	170	0

MILITARY COMBINED

AIRCRAFT EQUIPMENTS PHASE OUT - PHASE IN

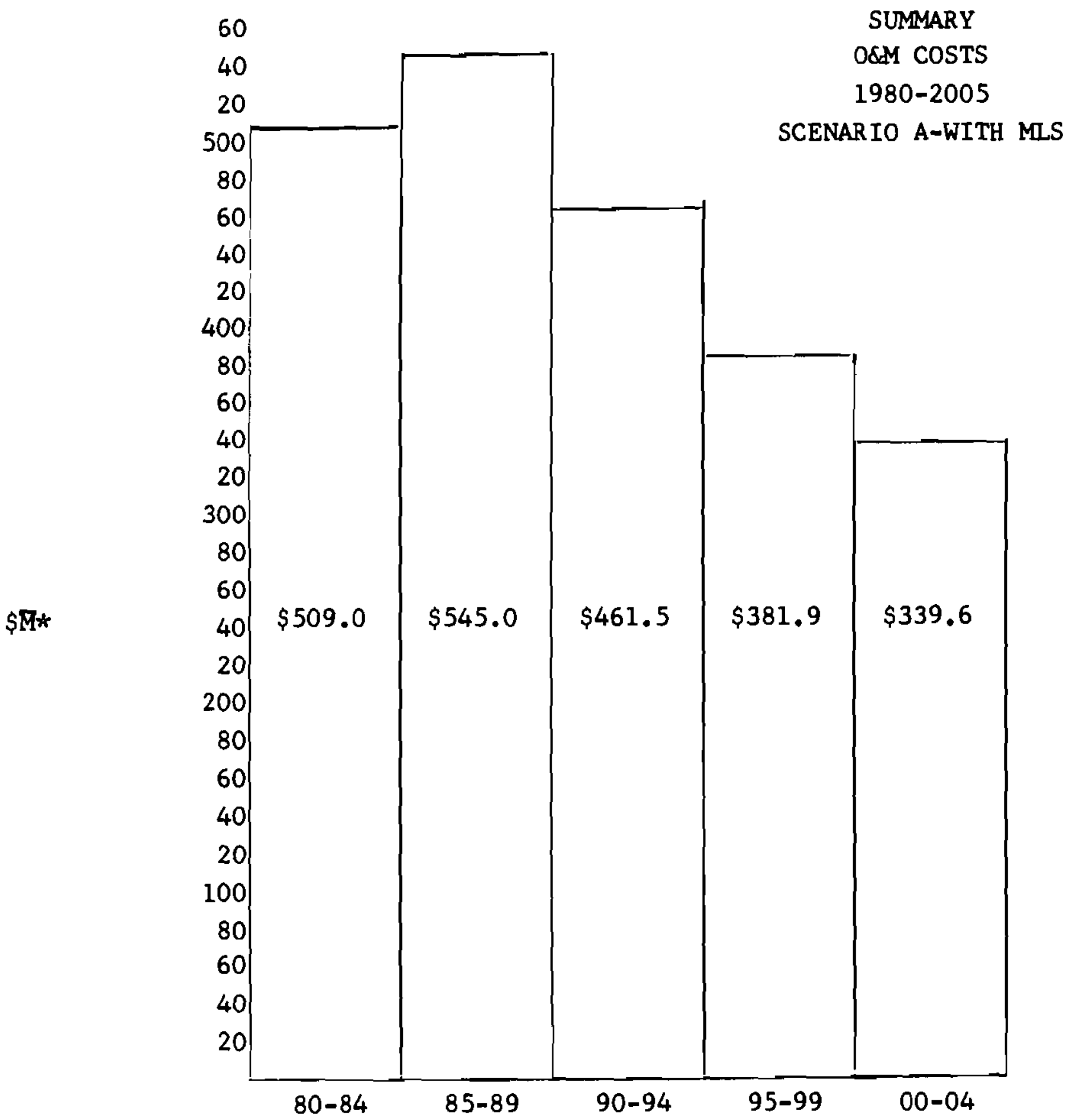
SCENARIO A - WITH MLS

CHART 2-36(A)

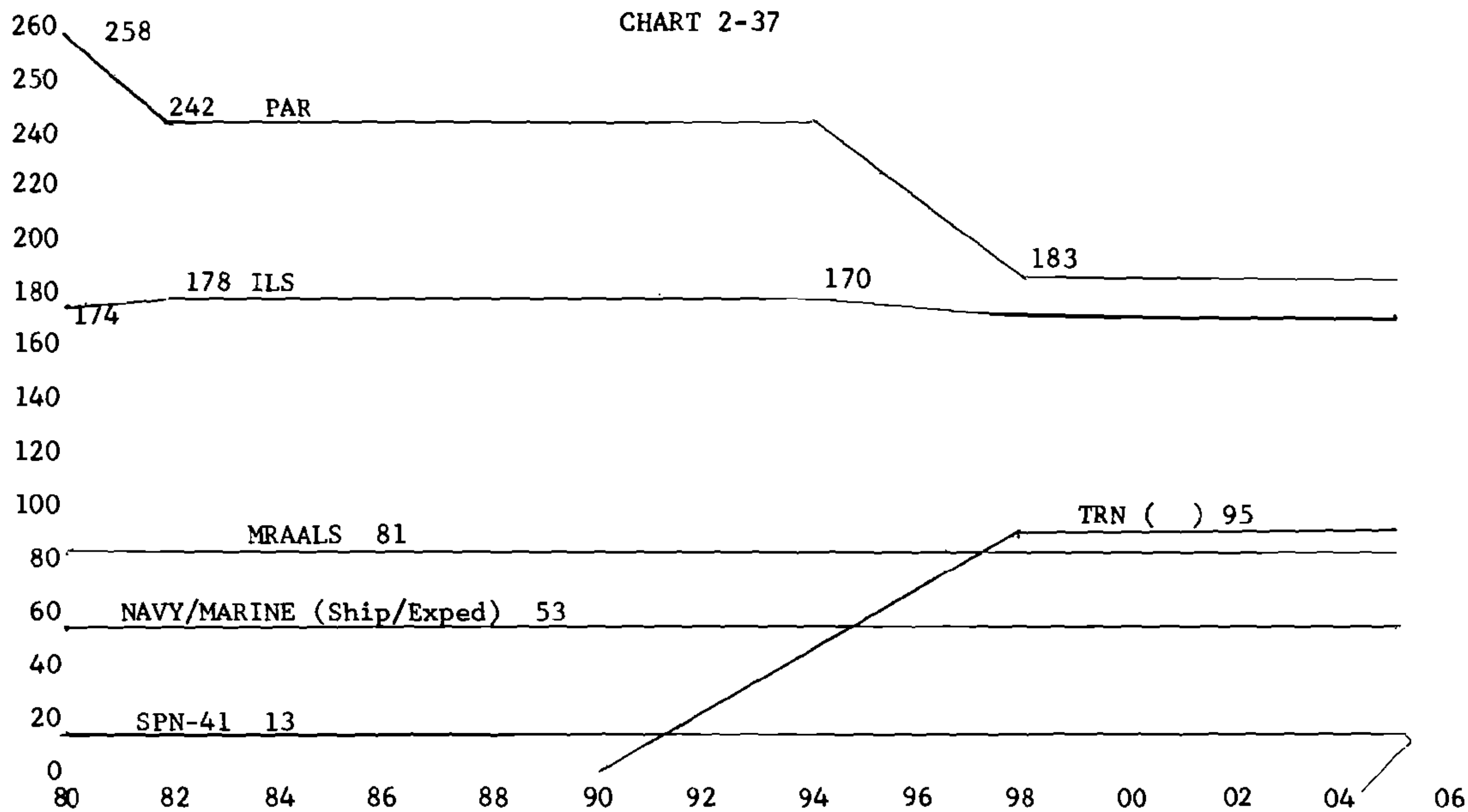


* Divide by 5 for average annual cost

CHART 2-36(B)



* Divide by 5 for average annual cost

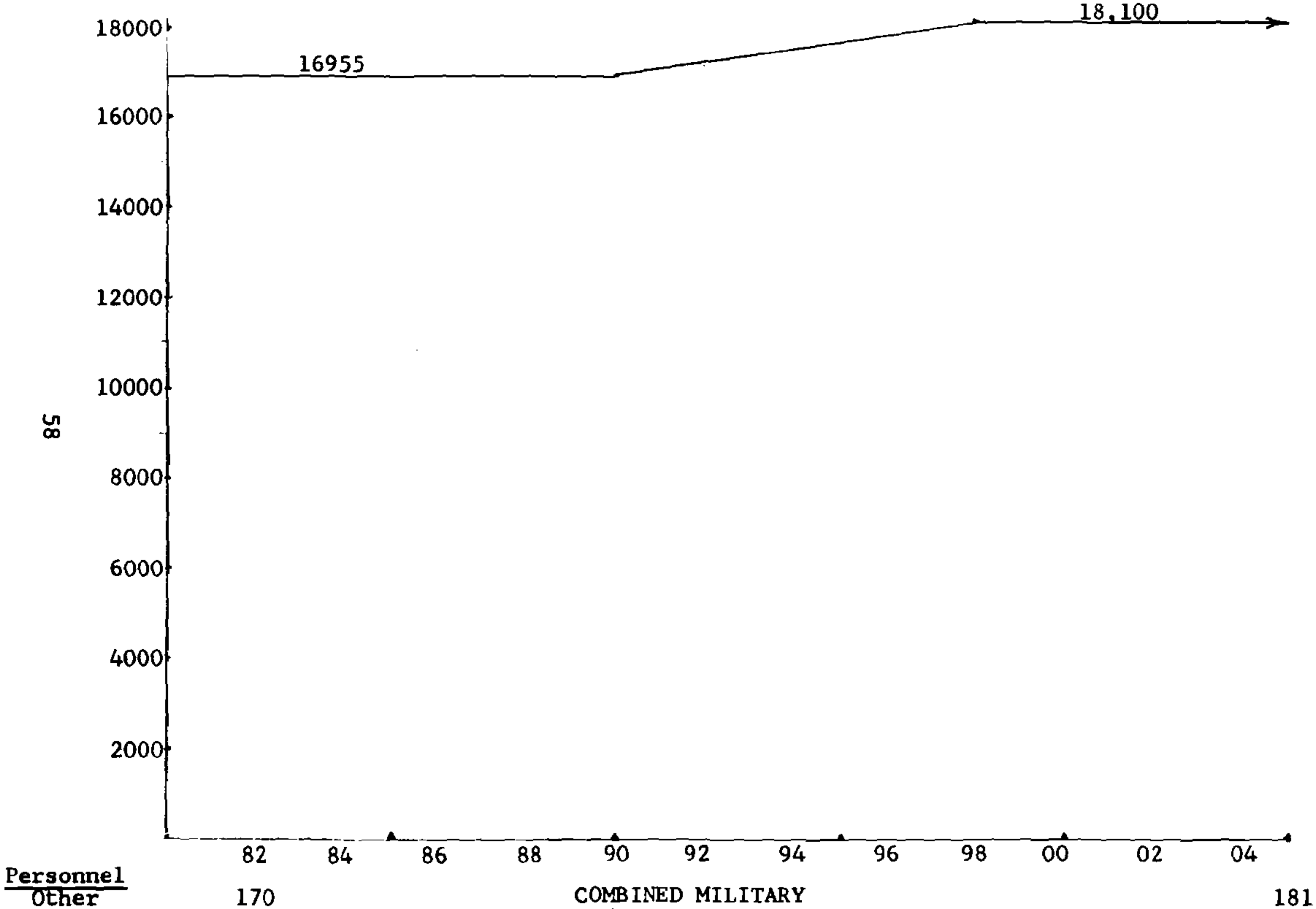


Personnel

PAR	2058	1338
ILS	522	510
MRAALS	192	192
TRN( )	0	285
Navy/ Marine (Ship/ Exped)	443	443
	3215	2768

MILITARY COMBINED SURFACE
EQUIPMENTS PHASE OUT - PHASE IN
SCENARIO B - NO MLS

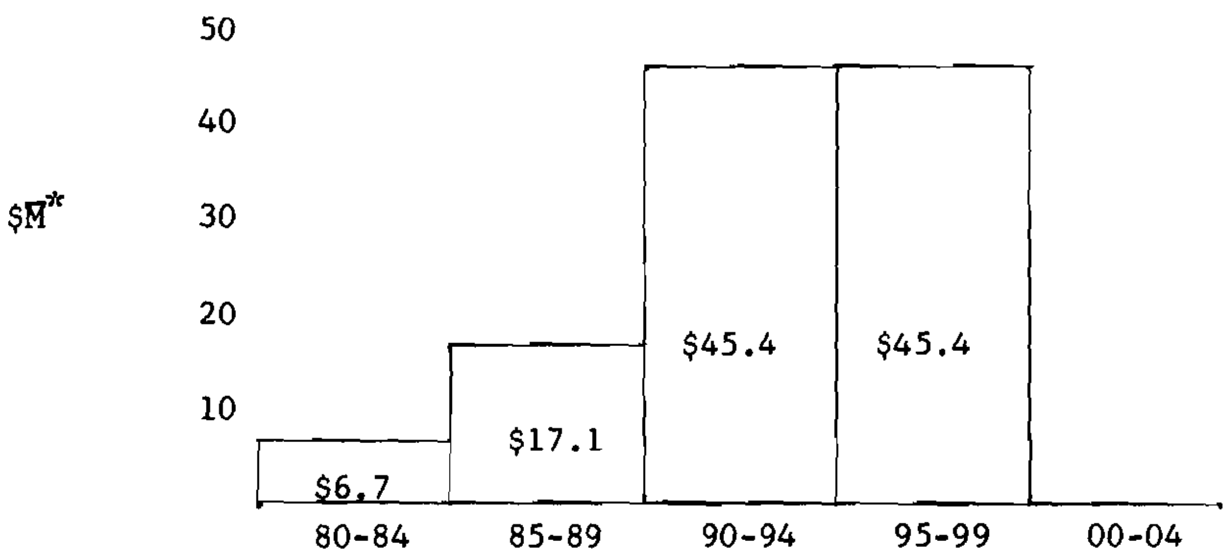
CHART 2-38



COMBINED MILITARY
AIRCRAFT EQUIPMENTS
SCENARIO B-NO MLS

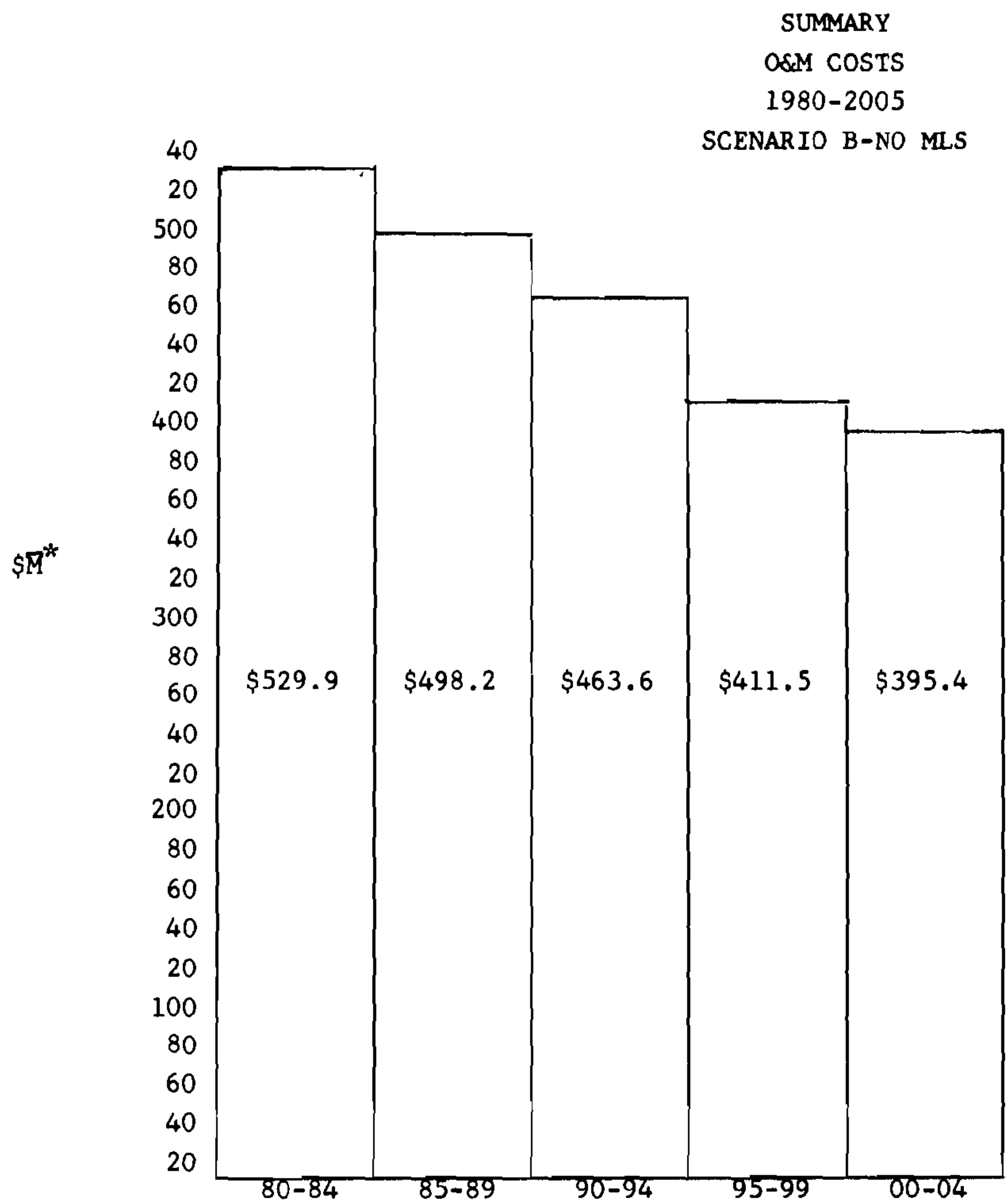
CHART 2-39(A)

SUMMARY
F&E COSTS
1980-2005
SCENARIO B-NO MLS



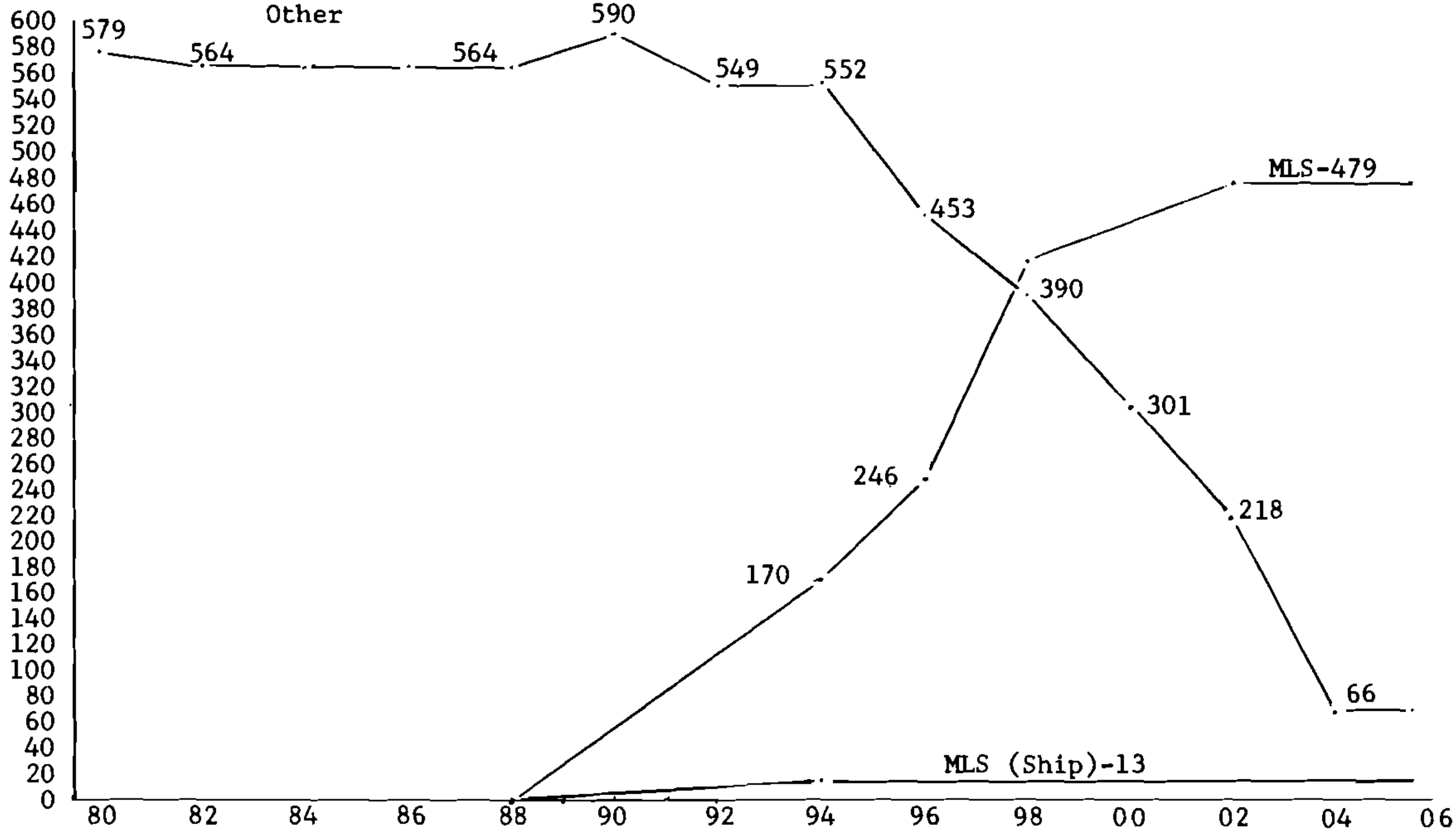
* Divide by 5 for average annual cost

CHART 2-39(B)



* Divide by 5 for average annual cost

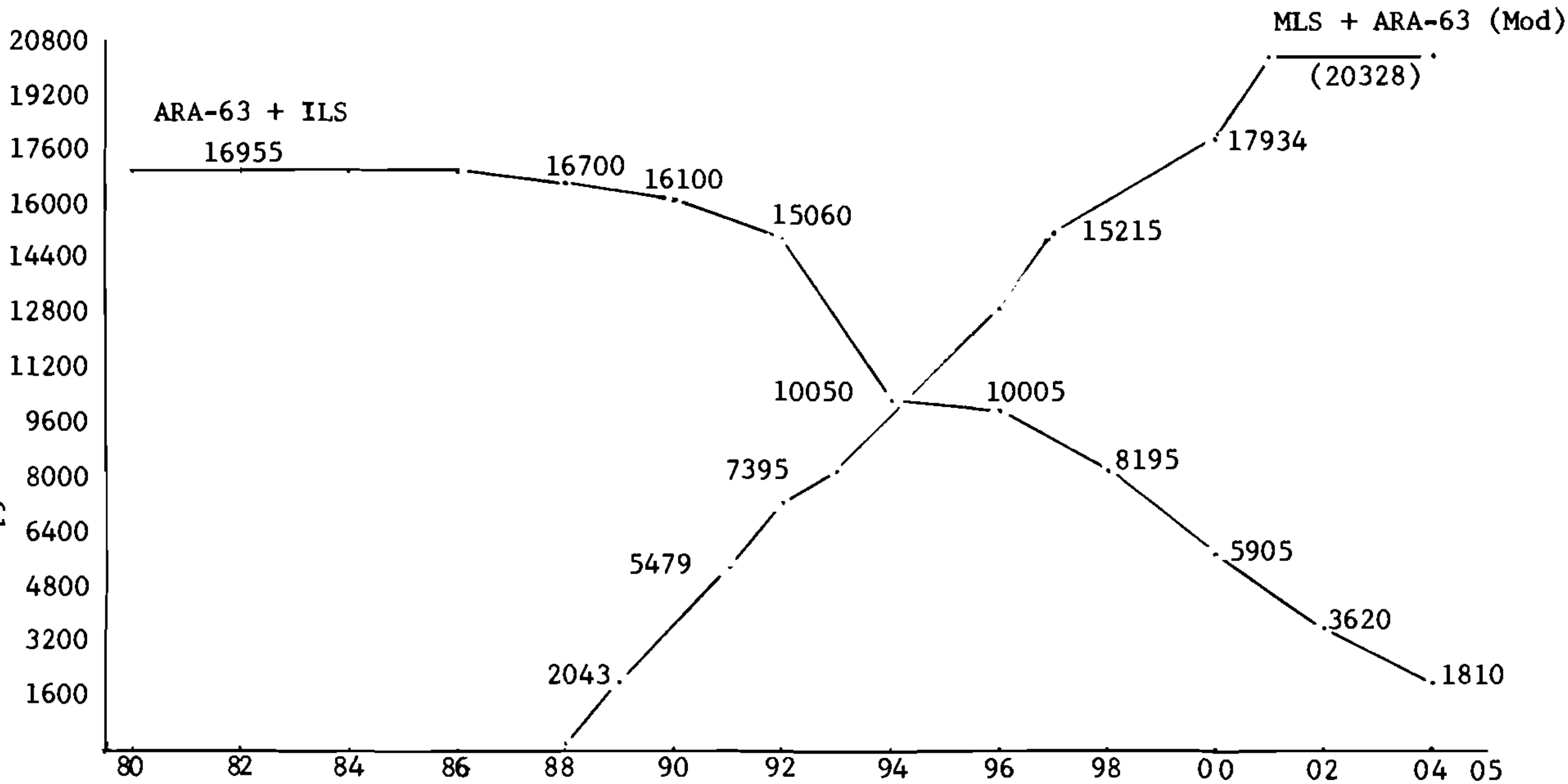
CHART 2-40



Personnel		
MLS	0	1441
Other	3215	0
Total	3215	1441

MILITARY COMBINED
SURFACE EQUIPMENTS PHASE OUT - PHASE IN
SCENARIO C - MLS DELAYED 5 YEARS

CHART 2-41



<u>Personnel</u>

MLS 0 ... 180
Other 170 ... 0

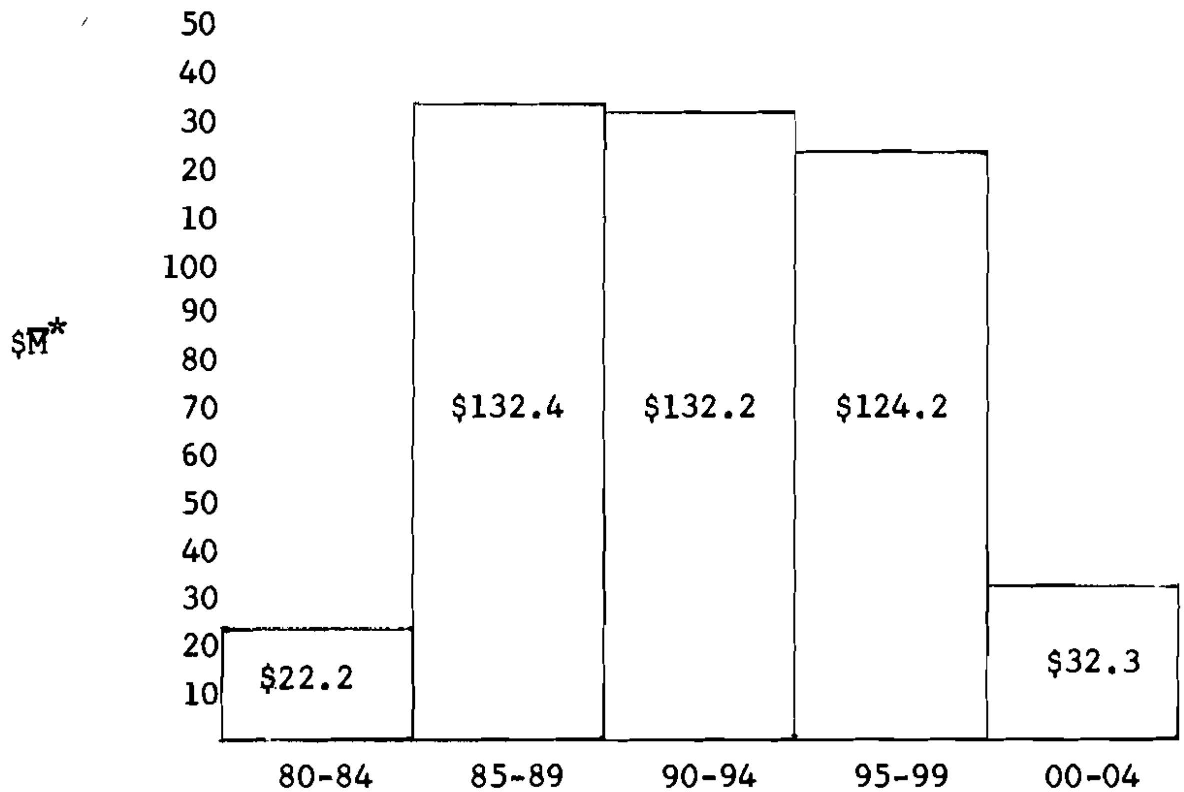
MILITARY COMBINED

AIRCRAFT EQUIPMENTS PHASE OUT - PHASE IN

SCENARIO C - MLS DELAYED 5 YEARS

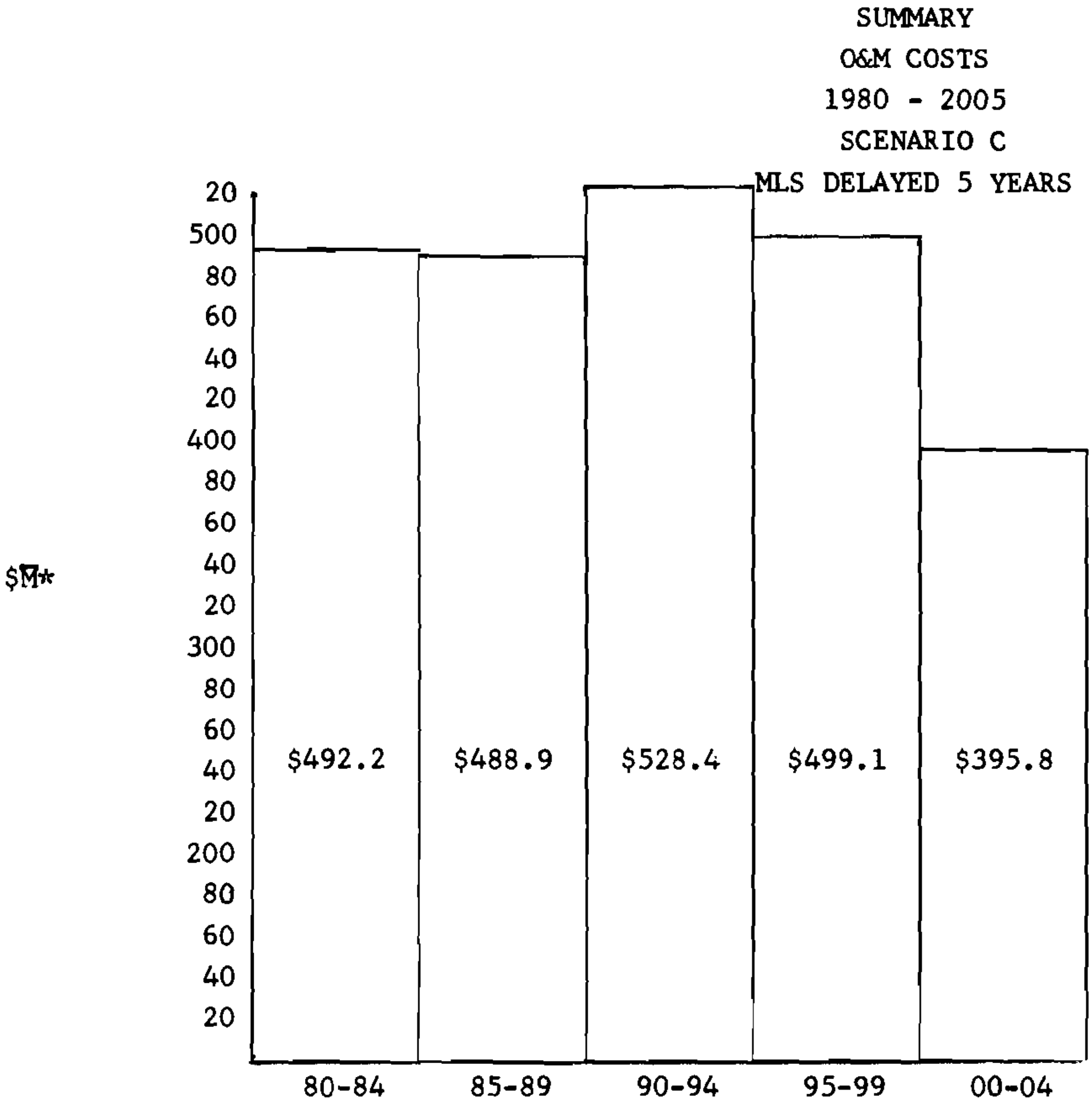
CHART 2-42 (A)

SUMMARY
F&E COSTS
1980-2005
SCENARIO C
MLS DELAYED 5 YEARS



* Divide by 5 for average annual cost

CHART 2-42 (B)

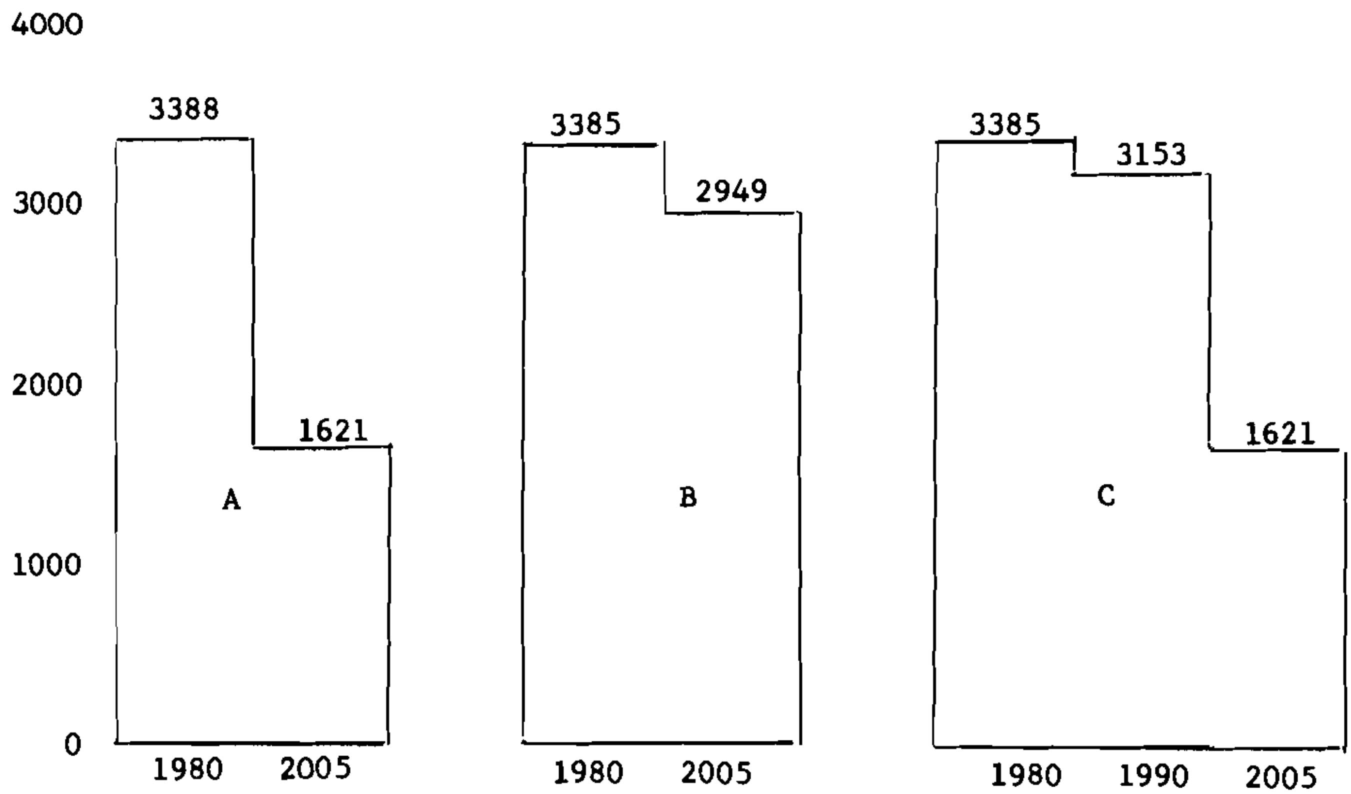


* Divide by 5 for average annual cost

CHART 2-43

PERSONNEL SUMMARY CHART

SCENARIOS A, B, and C



RESEARCH AND DEVELOPMENT

Historical R&D cost figures are based upon incomplete R&D costs over a ten year period for some of the more familiar military landing systems as shown in Chart 2-1. This chart shows efforts as follows:

Army	14.0M̄
Air Force	21.6M̄
Navy	30.9M̄
Marine Corps	6.4M̄

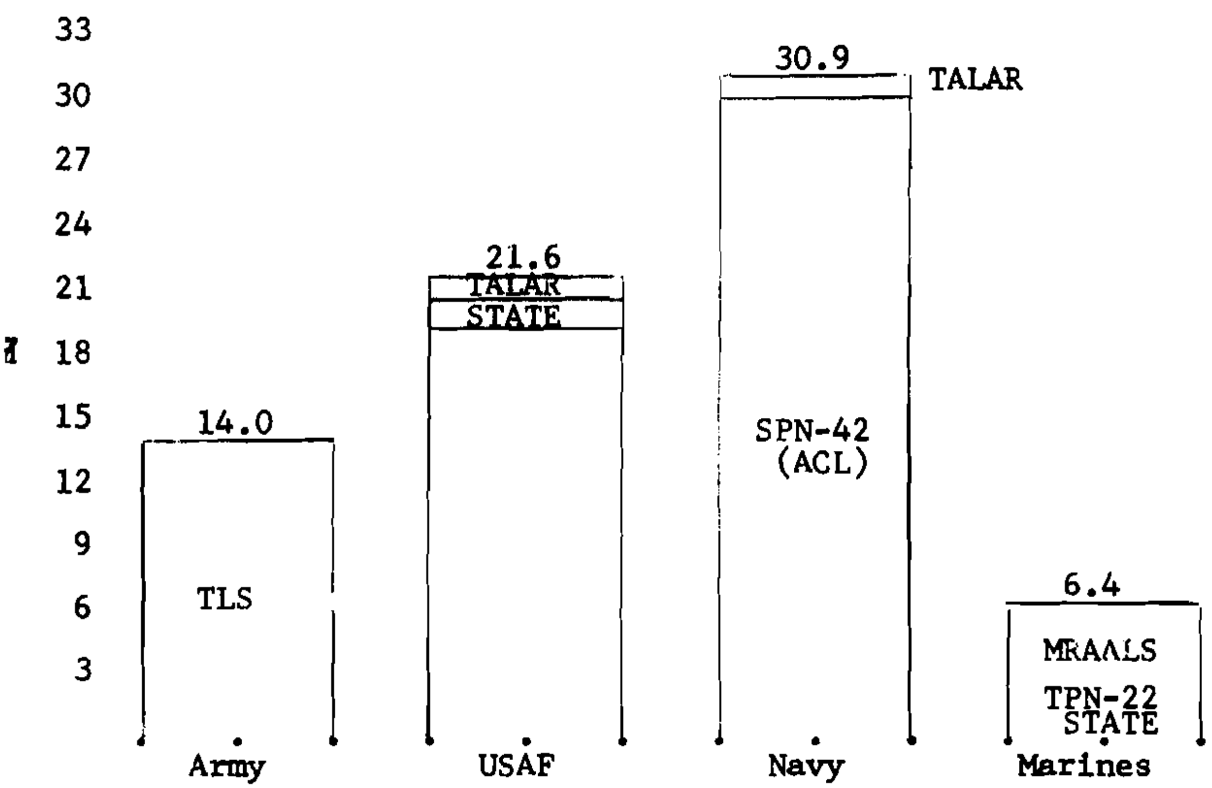
These figures show that the Services spent $7.3M̄ per year in support of TLS, TALAR, STATE, TPN-19, SPN-41, SPN-42 and TPN-22 developments. During this period the Military Services carried on a number of other study and development efforts which were not as significant and are not included in this estimate. These include FLARESCAN, GPN-5, TAILS, SAILS, etc. Also Military R&D funding as set forth above did not in most cases include the cost of prototype models used for test and evaluation. These models were commonly charged to production funds. Any future military development would have to include the cost of test and evaluation models as a matter of military procurement policy. Therefore the annual R&D cost to the Military in terms of 1974 dollars was assumed to be $14.6M̄ in Chart 2-2 vice $7.3M̄ in Chart 2-1 because:

(1) Systems developed during the period covered by Chart 2-1 are not included in the $7.3M̄,

(2) Funds in Chart 2-1 for the most part did not include contractual items which would be charged to R&D on any future procurement, and

(3) The $7.3M̄ is not representative of the 1974 costs for R&D indicated due to inflationary factors.

Chart 2-44

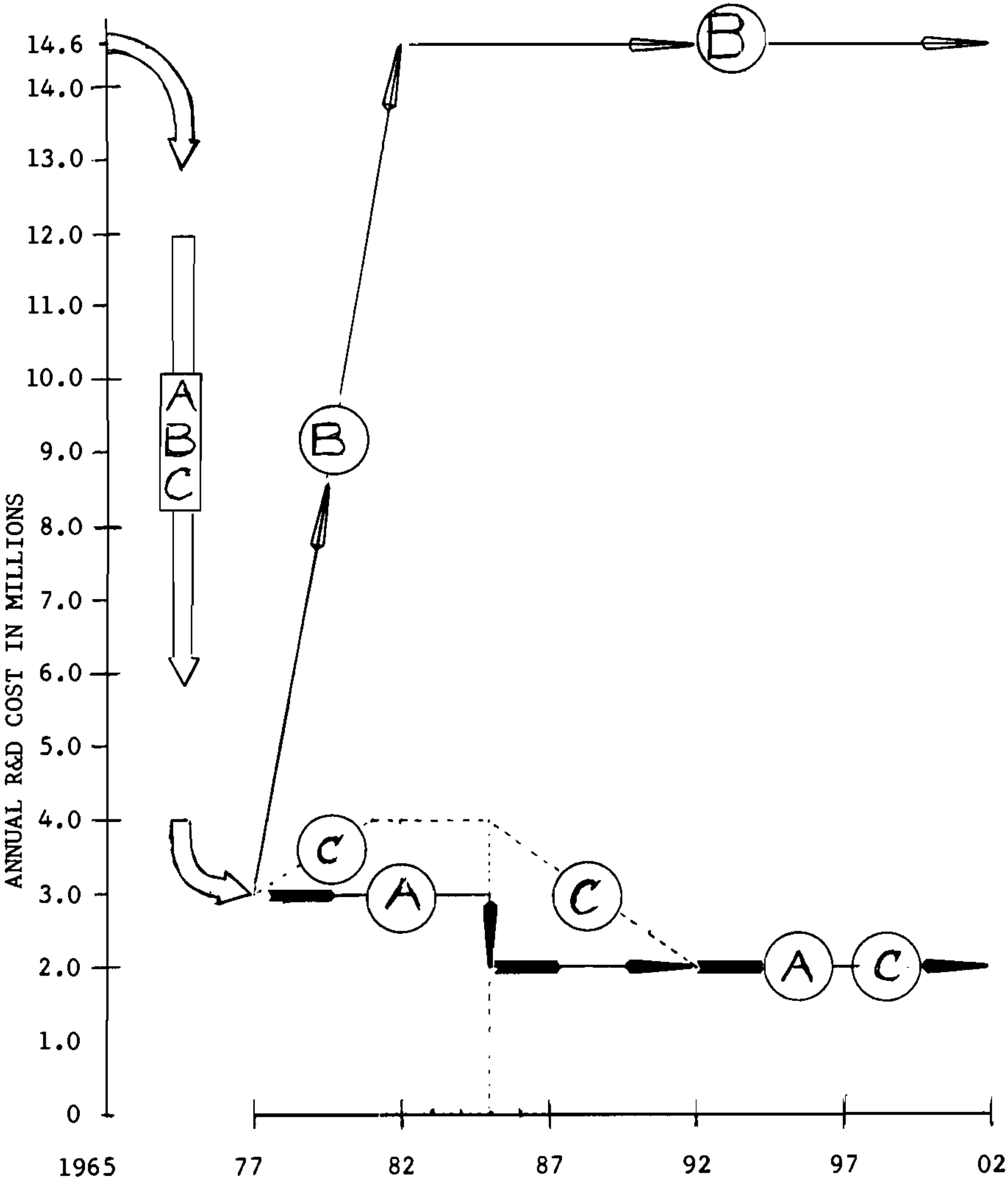


Military R&D Expenditures (Historical)

(Major Approach/Landing Systems)

(10 years)

R&D COSTS -- SCENARIOS A, B & C



SECTION III

BENEFITS OF CIVIL/MILITARY COMMONALITY

In Section II cost benefits of MLS are detailed. Most benefits--reduction in personnel, reduction in siting problems (shipboard and forward area), and capability to perform automatic landings--could be attained by Joint Military implementation of TLS, MRAALS or some derivative of these systems. This section only considers benefits which result from civil/military commonality. While these benefits are discussed in the context of commonality in the United States, the international commitment of the Military Services requires the commonality of an ICAO Standard.

These benefits of civil/military commonality have been addressed before in great detail. The discussion contained herein highlights the most important benefits to the Military Services.

Operational Benefits

Commonality would provide:

- Better Use of Airfields
- Better Use of Airspace
- Reduction Pilot Problems
- Better Use of the Frequency Spectrum

a. Better Use of Airfields--

A recent FAA Order 5190-2H identified 171 civil airfields as authorized for joint use by the Military Services. Of these only 4 were equipped with a GCA/PAR and would be usable by all the Services under IFR conditions. A common landing system could provide this capability at all 171 airfields.

The ability of the Military Services to use civil airfields for dispersion or deployment at times of crises or in preparedness exercises could be enhanced considerably by having landing system commonality.

The Services now use civil airfields to reduce overload at flight training facilities. It is often necessary that they bring along their own mobile landing system unit to provide the proper training environment. Commonality could eliminate this need.

Military aircraft with malfunctions or fuel shortages are often forced to divert to a military airfield due to the incompatibility of their landing system with a closer civil airfield ground environment. A forced landing under this situation represents a hazard to life and property.

b. Better Use of Airspace--

The use of a common civil/military landing system will simplify the problem of military enroute and approach controllers by standardizing control procedures. Also adjoining civil and military approach airspace can be better controlled if the aircraft is not required to change procedures when changing control.

In pilot declared emergencies where aircraft are forced to divert to a more distant airfield because of a landing system incompatibility, the military aircraft is occupying airspace unnecessarily and could cause delays and hazards to other aircraft.

c. Reduction in Pilot Problems--

Pilot stress is at its greatest during the landing maneuver. Military pilots are now required to learn procedures and controller terminology for more than one type of landing system. At times of stress, the differing procedures and terminology can represent a confusion factor. A common civil/military landing system should eliminate this problem.

Pilots who are qualified and ticketed to land under conditions of reduced visibility at military airfields will be equally qualified to land under the same conditions at civil airfields.

d. Better Use of the Frequency Spectrum--

The use of a common civil/military landing system will reduce the increasing demand for channels in some frequency bands and could possibly eliminate the needs for some assigned bands entirely. Commonality will permit a much more intelligent assignment of frequencies.

RDT&E and Procurement Benefits

This category of benefits would include:

- Expansion of the Engineering Base
- Shared RDT&E Costs
- Reduced Procurement Costs

a. Expansion of Engineering Base--

The past proliferation of civil and military landing systems has resulted in a wide split in the government/industry engineering community. Engineering talent has been divided into separate camps supporting specific systems both in government and industry. The development and procurement of a common civil/military landing system eliminates competing systems and provide a larger engineering base for the standard system. The system users should benefit from engineering competition.

b. Shared RDT&E Costs--

The current MLS procurement program is funded by FAA. The elimination of competing military developments has reduced R&D costs to the Military Services. Future R&D to satisfy peculiar requirements of a specific Service can limit effort to areas which are beyond the scope of the basic development. Refinement of the basic system can be carried on as a common shared endeavor. Test and Evaluation (T&E) would be performed in the same way with shared evaluation of the basic system and separate funding of tests performed to evaluate equipment built to meet peculiar Service requirements.

c. Reduced Procurement Costs--

With a common civil/military landing system the assumption is made that much of the hardware used by the Services on the ground will be similar to that being procured by the FAA. Likewise, some military aircraft equipment will be similar to that used by general aviation and commercial air transportation. This increased market for equipment meeting the same or similar specifications is expected to increase competition and reduce prices for all users. The Military Services as one of the principal users stands to benefit by this commonality of equipment requirements.

Training and Logistics Benefits

This category of benefits would include:

- Reduction in Training Costs
- Reduction in Logistic Support Costs

a. Reduction in Training Costs--

A reduction in the number of systems for which pilots, controllers and technicians must train will reduce training and proficiency flying requirements. This would reduce requirements at schools for instructors, representative landing component and training manuals. It also could reduce the number of training aircraft and simulators required.

The commonality of a civil/military landing system would permit the shared use of existing civil schools and training facilities.

b. Reduction in Logistic Support Costs--

Logistic costs which represent the hidden costs associated with maintenance of a system are particularly high in the Military Services. This is due in part to the military requirement to be able to function at any time in any part of the world. It requires that equipment, parts and maintenance personnel be prepositioned. Any reduction in the number of landing systems will result in proportional reduction in the logistic support costs. The use of a common civil/military landing system could further reduce logistic support costs since some of the support equipment and trained maintenance personnel would already be spotted world-wide in support of the civil/military systems of allied nations.

SECTION IV

Conclusions

Based upon the successful development of an ICAO approved MLS capable of fulfilling military tactical requirements, it is concluded that with implementation the Military Services could realize the following important benefits:

- A material reduction in the number of Precision Approach Radars with the attendant reduction in personnel and maintenance costs.
- Operational flexibility and mobility to satisfy military tactical requirements.
- Civil/military commonality to improve operational capability and reduce RDT&E, procurement, training and logistics costs.

It is concluded that, by replacing existing military landing systems with MLS, the annual Military Services' cost for Operation and Maintenance (O&M) would be reduced. The date at which this reduction would be realized is dependent upon the implementation plan or scenario used. The annual O&M costs could be reduced in Scenario A from the current $101.5 rate to a rate of $64.6 on completion of implementation. Much of this cost reduction stems from a reduction of operator and maintenance personnel from 3388 to 1621.

Implementation Scenarios A, B, C and D are described in Section II along with personnel and funding changes in a 25 year period from 1980 to 2005.

It is concluded further that much of the cost savings, operational flexibility and system mobility could be achieved by Services' standardization on one of two existing military microwave landing systems. Only by obtaining civil/military commonality on an ICAO approved MLS can the important benefits of civil and international interoperability be exploited. Civil and international interoperability are firm USAF requirements. The benefits of civil/military commonality are highlighted in Section III.

APPENDIX A

INVENTORY OF MILITARY APPROACH AND LANDING EQUIPMENTS/SYSTEMS

DEFINITIONS

NAVY

PAR A -- Large fixed Precision Approach Radar (PAR) for use ashore. Air Controller on ground talks pilot down. All military aircraft can use. Nomenclature -- CPN-4, FPN-52.

PAR B -- Small fixed or mobile Precision Approach Radar (PAR) for use ashore. All military aircraft can use. Nomenclature -- FPN-36.

SPN-35 -- Same as PAR B. Used aboard ships for CTOL and VTOL aircraft. Same as TPN-8 with roll and pitch stabilization.

TPN-8 -- Same as PAR B. Used ashore by Marine Corps for CTOL and VTOL aircraft.

SPN-42 -- MLS for automatic landings of high performance aircraft aboard aircraft carriers. Data link from ship to aircraft used for aircraft control. Pilot has crosspointer display. Shipboard consoles for carrier controlled approach or for monitoring automatic on pilot controlled approaches.

SPN-41 -- MLS used aboard ship for pilot to monitor automatic landing system control (SPN-42). Pilot has crosspointer display. Is also used as primary approach system for carriers not having SPN-42.

ARA-63 -- Airborne receiver and decoder for SPN-41 and MRAALS signals.

MRAALS -- Marine Remote Area Aircraft Landing System (MRAALS). Same azimuth and elevation signal as SPN-41. Has L-band DME. Is man transportable. Initial procurement expected March 1975. Used by VTOL aircraft. Replaces TPN-8.

MATCALS -- Marine Air Traffic Control and Landing System (MATCALS). Has automatic landing system (TPN-22) which is similar to SPN-42. Requires data link. Used by high performance aircraft. Procurement started in CY 1974.

ILS -- Instrument Landing System. Same as civil. Fixed base operations only.

ARMY

PAR B -- Small fixed or mobile Precision Approach Radar used for normal and tactical operations. Nomenclature -- FPN-40, TPN-18.

ILS -- Instrument Landing System. Same as civil. Fixed base operations only.

TLS -- MLS Tactical Landing System similar to SPN-41. Will have airborne receiver/decoder similar to ARA-63. Has been in R&D since mid-sixties. Not planned for operational use if common MLS goes on schedule.

USAF

PAR A -- Large fixed or mobile Precision Approach Radar for use ashore in manual and tactical operations. Mobile -- CPN-4; MPN-11; MPN-13 Fixed -- FPN-16

TPN-19/ GPN-XX -- Same as PAR A. Procurement started CY'74 for 2 prototype, 9 production. GPN-XX procurement planned.

ILS -- Instrument Landing System. Same as civil. Fixed base operations only.

SSILS -- Solid State ILS.

TALAR -- Tactical landing system of the MLS type. Small quantity procured.

STATE -- Tactical landing system developed but none planned operational.

CURRENT AND PROJECTED EQUIPMENTS/SYSTEMS

Equipment/Systems	Current No.	Projected (FY'75-'79)
NAVY		
PAR A/B	65	Solid State Mod. Program started. Reduce to 59 upon completion
SPN-35	18	No change. Removed from some aircraft carriers and installed on ships (LHA/LPD) for Marine Corps amphibious operations
TPN-8	43	Phase out as replaced by MRAALS
SPN-42/42T	17	No change except for new aircraft carriers being built
SPN-41	15	No change
ARA-63	1800 (installed)	Building to 2100 for CTOL and 950 for VTOL
MRAALS	81	No change.
MATCALS	17	No change. Procurement started CY'74
ILS	4	No change
ARMY		
PAR B	115	No change
ILS	5	No change
TLS	6 (in R&D)	Depends MLS
USAF		
PAR A	132	Reduce to 83 by 1980
TPN-19	11	GPN-XX being procured
ILS	105	Increase to 161
TALAR	40 ground/ 400 air	No change

APPENDIX B

MANNING TABLE

Ground Equipment

Equipment	Rate	Pay Grade Level	Life Cycle Cost/Yr.	Total Personnel Cost/Unit/Year
PAR A (CPN-4, FPN-52, MPN-11, MPN-13 FPN-16, SPN-42/ 42T, TPN-22)	6 AC 4 ET	E-6/E-5 E-5/E-4	22,756/16,551 18,813/16,421	117,921 70,468
				188,389
PAR B (FPN-36, 40, TPN-18)	4.5 AC 1 ET	E-5/E-4 E-4	16,551,13,964 16,421	68,661 16,421
				85,082
ILS (Ground) 24-Hour	3 ET	E-5(1)/E-4 (2)	18,813 16,421	18,813 32,842
				51,655
SPN-35/TPN-8	4.5 AC 1 ET	E-5/E-4 E-4	16,551/13,964 16,421	68,659 16,421
				85,080
SPN-41/TRN-28/ (Monitor)	3 ET(10%)	E-3	14,268	4,280
SPN-41/TRN-28/ MRAALS (Primary) 24-Hours	3 ET	E-3	14,268	42,804
MLS (Ground)	3 ET	E-5(1)/E-4 (2)	18,813 16,421	18,813 32,842
				51,655
MLS (Ship Mon)	3 ET(10%)	E-3	14,268	4,280
Aircraft Equipments				
ILS (Air)	1 ET/ 100 Acft	E-4	16,421	164
ARA-63 (CAT II)	1 ET/ 100 Acft	E-4	16,421	164
MLS (Air) CAT I	1 ET/ 150 Acft	E-4	16,421	109
CAT II	1 ET/ 100 Acft	E-4	16,421	164
CAT III	1 ET/ 50 Acft	E-4	16,421	328

APPENDIX C

MILITARY PERSONNEL PAY AND SUPPORT COSTS

Source: U.S. Naval Personnel Program Support Activity

The personnel costs for military air traffic control and maintenance technician personnel used in computing operating and maintenance cost factors in PAR, ILS, military MLS and common MLS facilities and equipments were derived from a USN model. The total billet cost shown below is a total of base pay plus factors for FICA, constant cost per grade, constant cost per year, proficiency pay, school cost, transportation cost, reenlistment and settlement cost, retirement contribution, plus a "down"-cost. The "down" cost is that cost incurred to keep the billet filled during leave, TDY, sickness, AWOL, suspensions, etc. This personnel cost model produced by the U.S. Navy was used because it more nearly represents the cost to have and maintain an enlisted member of the armed force at any point in or for the total military career. It is assumed that cost variations between the Air Force, Army, Navy and Marine Corps will be insignificant.

Grade	Total Billet Cost Per Year	
	Air Control-Man (AC)	Elect. Tech (ET) *
E-2	$ 12,328.00	$ 13,892.00
E-3	$ 12,704.00	$ 14,268.00
E-4	$ 13,964.00	$ 16,421.00
E-5	$ 16,551.00	$ 18,813.00
E-6	$ 22,756.00	$ 21,900.00
E-7	$ 25,863.00	$ 26,158.00
E-8	$ 28,857.00	$ 26,690.00
E-9	$ 36,631.00	$ 34,354.00

* The Navy/USMC maintain airborne electronic equipment using an Aviation Electronics Technician (AT). Since the other services apparently do not have this classification, the pay scale for an ET was used in establishing airborne electronic equipment maintenance costs for all services.

AIRCRAFT NUMBERS AND ECP COST FOR MLS

	Category	Cost $M Type	No. Types	No. Aircraft	Aircraft Types
NAVY	I (Trns)	1.0	1	335	Training
	II (T)	1.5	3	810	VP, EW, Transport
	II (H)	No ECP ARA-63( )	3	1,244	F4, F-14, F-18
	II (H)	1.0 *	3	756	A-6, A-7, S-3
	II (V/STOL)	.5	4	955	CH-46, CH-53, UH-IN, AV-8
	III (H)	1.5	6	2,000	F-4, F-14, F-18, A-6 A-7, S-3
ARMY	I	1.0	8	7.178	UTTAS, AAH, UH-1, CH-54 CH-47, Mohawk OV-1 Cobra
USAF AVIONIC (MLS) COSTS					
	I	1.0	5	2,538	A-10; A-37; T-37; UH-1; OV-10
	II (Hi)	2.0	6	2,988	A-7; F-4; F-15; F-111; LWF; T-38
	II (Tr)	1.5	9	2,704	B-1; B-52; KC-135; C-9; C-130; AMST; T-39; T-43; HH-53
	III (Hi)	3.0	2	280	F-106; RPV
	III (Tr)	2.0	2	540	C-5; C-141

* ECP cost has been reduced where MLS replaces ARA-63 equipment.

APPENDIX E

Estimates for Military Air Fleet Strengths
(1978 - 1987)

Year	USAF	USA	USN/MC	Total in U.S.
1978	8821	6880	4207	19,908
1979	8800	6954	4120	19,874
1980	8859	7021	4055	19,935
1981	9054	7111	3989	20,154
1982	9054	7178	4036	20,208
1983	9054	7178	4070	20,302
1984	9054	7178	4070	20,302
1985	9054	7178	4070	20,302
1986	9054	7178	4070	20,302
1987	9054	7178	4070	20,302

APPENDIX F

DEFINITIONS

GROUND EQUIPMENTS

ADVANCED MLS

This system is the military equivalent of the Civil Expanded MLS configuration capable of supporting ICAO Category III objectives on long runways at fixed bases. The system includes angle guidance, distance measurement, flare guidance and a back azimuth element. Redundant subsystems with automatic changeover are provided. This system would provide autoland with roll out.

STANDARD MLS

This system is the military equivalent of the Civil Basic Wide MLS configuration capable of supporting ICAO Category II objectives. It has the inherent performance of the Advanced MLS but omits the flare guidance and back azimuth elements. This system would provide autoland except the flare maneuver.

AUSTERE MLS

This system is the military equivalent of the Civil Basic Narrow MLS configuration capable of supporting ICAO Category II objectives depending on runway length. This system provides lower resolution beams and hence lower accuracy than the Standard MLS. This system would provide autoland for VTOL and STOL aircraft.

TACTICAL MLS

Equipment designed for deployment in unimproved tactical landing areas in world-wide operational environments. This system is the same as Austere MLS except would have transportability, flexibility, and quick set up time.

APPENDIX F

DEFINITIONS

AIRBORNE EQUIPMENTS

The designations "T" (transport) and "H" (high performance) are used for Air Force systems to associate the installation costs with type of aircraft because of the higher cost of installation in high performance aircraft.

The provision of ancillary curved path computer and associated display equipment for full exploitation of MLS is not considered part of the MLS airborne equipment for cost analysis because of lack of definition.

ADVANCED MLS

This equipment is the military equivalent of the Civil Expanded MLS aircraft configuration capable of supporting ICAO Category III objectives. The system includes angle (including back azimuth and flare) receiver/processor, DME transponder, full auxiliary data display, self-test monitoring and redundancy.

STANDARD MLS

This equipment is the military equivalent of the Civil Basic MLS aircraft configuration, capable of supporting ICAO Category II objectives. This equipment includes angle receiver/processor, DME transponder, full auxiliary data display, self-test and monitoring. This system would provide fully automatic landing except the flare maneuver.

AUSTERE MLS

This equipment is not directly equivalent to a civil MLS configuration (the closest equivalent would be a Small Community airborne equipment with the addition of a selectable glideslope and DME transponder). The equipment has reduced self-test, monitoring and auxiliary data display and is capable of supporting ICAO Category I operation and Category II operation for STOL and VTOL aircraft.

APPENDIX G

LIST OF PERSONS CONTACTED

Miss E. Bibb	Naval Electronics Systems Command
MAJ R. Brady	USAF, Office of Dep. Chief of Staff, Plans and Operations
COL J. Diven	USAF, Office of Dep. Chief of Staff, Plans and Operations
Mr. J. Ennis	Naval Weapons Engineering Support Activity
LTC D. Goodson	USAF, Office of Dep. Chief of Staff, Research and Development; Chairman, SC-125, Informal Military Planning and Cost Group
Mr. C. Grabher	Secretary, RTCA, SC-125
CAPT G. Groehn	Federal Aviation Administration (USN Liaison)
Mr. W. Holliman	Bureau of Naval Personnel
Mr. S. Horowitz	Federal Aviation Administration
Mr. R. Jacks	United Air Lines; Chairman, SC-125, Informal Civil Cost Group
LTC W. Johnson	Office of Dep. Chief of Staff, Research, Development and Acquisition
Mr. J. Kouchakdjian	Federal Aviation Administration
COL W. Larimer	DOD, Office of Dep. Director of Research and Engineering
Mr. R. Lehto	Bureau of Naval Personnel
Mr. O. Lietzke	USAF, Chairman, SC-125, Informal Benefits Group
Mr. J. McKeeman	Army Aeronautical Services Office
Mr. G. Miller	Naval Electronics Systems Command
Mr. A. Niles	Naval Air Systems Command
Mr. W. Oehrle	Republic Electronic Industries Corp.
CDR L. O'Neil, Jr.	Naval Safety Center
CAPT Ortega	Office of Dep. Chief of Naval Operations (Air Warfare)
Mr. K. Peterson	DOD, Office of Manpower and Reserve Activities
LTC C. Phillips	Federal Aviation Administration (USA Liaison)

Mr. W. Raynor	Naval Electronics Systems Command
Mr. W. Reddick	Federal Aviation Administration
Mr. G. Rehrig	Federal Aviation Administration
Mr. C. Taylor	Naval Air Systems Command
Mr. Thomas	Marine Corps Development Center, Air Branch (Quantico, Virginia)
Mr. D. Tuttle	Office of Dep. Chief of Naval Operations (Air Warfare)
CAPT A. Warnack	Marine Corps Headquarters, Requirements and Programs Division
LTC G. Wendland	Federal Aviation Administration (USAF Liaison)

USAF DATA SHEET

MLS EQUIPMENT		INSTALLATION COSTS/U			
CLASS	NO.	N-R COST	N-R COST/U	INST COST/U	TOTAL/U
Fixed Austere	5	--	--	162,800	162,800
Standard	150	--	--	222,200	222,200
Advanced	61	--	--	506,800	506,800
Tactical Split Site	20			37,000*	37,000
Aircraft Austere (T)	1178	2,000,000	1,700	1,500	3,200
Austere (H)	1360	3,000,000	2,200	5,000	7,200
Standard Single (T)	540	3,000,000	5,600	8,500	14,100
Standard Dual (T)	2164	10,500,000	4,900	15,000	19,900
Standard Single (H)	2988	12,000,000	4,000	25,000	29,000
Advanced Dual (T)	540	4,000,000	7,400	20,000	27,400
Advanced Single (H)	280	6,000,000	21,400	30,000	51,400

* SUPPORT COST ONLY

TABLE ONE (A)

USAF DATA SHEET

MLS EQUIPMENT			O & M COSTS/U/YEAR			
CLASS	NO.	COST/U	PERS COST	P.L.S, & S.C.	FLIGHT CK	TOTAL/ U/YEAR
Fixed Austere	5	98,800	52,000	7,500	5,000	64,500
Standard	150	213,400	52,000	10,000	10,000	72,000
Advanced	61	516,800	52,000	18,000	12,000	82,000
Tactical Split Site	20	250,000	52,000	8,000	5,000	65,000
Aircraft Austere (T)	1178	8,000	109	300	--	409
Austere (H)	1360	8,000	109	300	--	409
Standard Single (T)	540	15,800	164	680	--	844
Standard Dual (T)	2164	34,300	164	680	--	844
Standard Single (H)	2988	14,600	164	680	--	844
Advanced Dual (T)	540	36,100	328	1,100	--	1,428
Advanced Single (H)	280	16,400	328	1,100	--	1,428

TABLE ONE (B)

EQUIPMENT		O & M COSTS/U/YEAR			
CLASS	NO.	PERS. COST	P,L.S, & S.C.	FLIGHT CK	TOTAL/ U/YEAR
Fixed Mobile (PAR A)	83	188,389	127,247	4,000	319,636
Fixed ILS	157	51,655	10,025	21,275	82,955
Fixed SSILS	157	51,655	10,025	21,275	82,955
Fixed MLS (Fixed) Standard	216	52,000	10,000	10,000	10,000
Aircraft ILS	5693				

TABLE ONE (C)

NAVY/MARINE CORPS DATA SHEET

	MLS EQUIPMENT			INSTALLATION COSTS/U			
	CLASS	NO.		N-R COST	N-R COST/U	INST COST/U	TOTAL/U
Ship	Standard	13	500,000	--	--	200,000	200,000
Ground	Standard (Fixed)	95	213,400	--	--	222,200	222,200
	Tactical (Single)	45	120,000	--	--	18,000*	18,000*
	Tactical (Split Site)	17	250,000	--	--	37,000*	37,000*
Aircraft/types							
1	Austere (CAT I)	335	8,000	1,000,000	2,985	2,500	5,485
4	Austere (CAT II)	955	8,000	2,000,000	2,094	2,500	4,594
3	Standard (CAT II)H **	756	14,600	3,000,000	3,968	25,000	28,968
3	Standard (CAT II)H ***	1244	8,500	--	--	2,000	2,000
3	Standard (CAT II)T ****	810	34,300	4,500,000	5,555	15,000	20,555
6	Advanced(CAT III)H	2000	16,400	9,000,000	4,500	10,000	14,500

* Support Cost Only

** High Performance - Single Installation

*** ARA-63 (   )

**** Transport, Patrol, Recon - Dual Installation

TABLE TWO (A)

NAVY/MARINE CORPS DATA SHEET

MLS EQUIPMENT			O & M COSTS/U/YEAR			
	CLASS	NO.	PERS COST	P.L.S.	FLIGHT	TOTAL
Ship	Standard	13	52,000	47,000	10,000	109,000
Ground	Standard (Fixed)	95	52,000	10,000	10,000	72,000
	Tactical (Single)	45	52,000	8,000	5,000	65,000
	Tactical (Split Site)	17	52,000	8,000	5,000	65,000
Aircraft/types						
1	Austere (CAT I)	335	109	300	--	409
4	Austere (CAT II)	955	109	300	--	409
3	Standard (CAT II)H**	756	164	680	--	844
3	Standard (CAT II)H***	1244	164	680	--	844
3	Standard (CAT II)T****	810	164	680	--	844
6	Advanced (CAT III)H	2000	328	1,100	--	1,428

* Support Cost Only

** High Performance - Single Installation

*** ARA-63 ( )

**** Transport, Patrol, Recon - Dual Installation

TABLE TWO (B)

NAVY/MARINE CORPS DATA SHEET

EQUIPMENT			O & M COSTS/U/YEAR			
	CLASS	NO.	PERS. COST	P,L.S, & S.C.	FLIGHT CK	TOTAL/ U/YEAR
Ship	SPN-35	18	85,080	22,000	4,000	111,080
	SPN-41 (Monitor)	13	4,702	25,000	2,500	32,202
Ship/Shore	SPN-42/42T	17	188,389	125,000	80,000	393,389
	½SPN-42/42T	17	85,080	65,000	15,000	165,080
Ground	Fixed Mobile(PAR-A)	59	188,389	127,247	4,000	319,636
	TRN-28	8	42,804	10,000	10,000	62,804
	TPN-8 (Tactical)	43	85,080	22,000	4,000	111,080
	MRAALS (Tactical)	81	42,804	8,800	5,000	56,604
	ILS	4	51,655	10,025	21,275	82,955
	TPN-22	17	188,389	125,000	80,000	393,389
Aircraft	Standard (ARA-63)	3,100	164	680	--	844
	Standard (ILS)	950	164	680	--	844

TABLE TWO (C)

ARMY DATA SHEET

EQUIPMENT							
	CLASS	NO.	COST/U	N-R COST	N-R COST/U	INST COST/U	TOTAL/U
Ground	Fixed-Austere	24	98,800			162,800	261,600
	Fixed-Standard	3	213,400			222,200	435,600
	Tactical - Army	79	150,000			22,000*	172,000*
Aircraft	Austere (CAT-II)	7,178	10,900	7,000,000	975	2,500	3,475

* Support cost only

TABLE 3 (A)

ARMY DATA SHEET

EQUIPMENT			O & M COSTS/U/YEAR			
	CLASS	NO.	PERS COST	P,L.S, & S.C.	FLIGHT CK	TOTAL U/YEAR
Ground	Fixed-Austere	24	52,000	7,500	5,000	64,500
	Fixed-Standard	3	52,000	10,000	10,000	72,000
	Tactical - Army	79	52,000	8,000	5,000	65,000
Aircraft	Austere (CAT-II)	7,178	109	300		409

REPLACED EQUIPMENT COSTS

Ground	Fixed (PAR-B)	42	85,082	22,000	4,000	111,082
	Tactical (PAR-B	74	85,082	20,000	4,000	109,082
	Fixed (ILS)	5	51,655	10,025	21,275	82,955
Aircraft	Austere (ILS)	4,000	164	680		844

TABLE 3 (B)

MILITARY MLS GROUND SYSTEM UNIT COSTS - NON RECURRING
(Thousands)

Advanced (Dual) Cost/Unit

	Equip*	Support**	Install-Const***	Other ****	Total
Az	98.5	38.3	39.9	37.5	
El-1	77.5	38.3	39.9	37.5	
El-2	95.4	36.5	38.0	35.7	
Back Az	61.4	20.1	20.9	19.6	
Precision DME	70.0	9.1	10.7	7.7	
Synch	15.0	10.9	11.4	10.7	
Remote Equip	99.0	14.6	15.2	14.3	
Total	516.8	167.8	176.0	163.0	506.8

* No marker beacons

** Support includes spares, test equipment, documentation

*** Inst. constr. includes turnkey construction cost and turnkey installation cost

**** Other includes flight inspections, checkout, engineering overhead, utilities

TABLE FOUR (A)

MILITARY MLS GROUND SYSTEM UNIT COST - NON RECURRING
(Thousands)

Standard (Dual) Cost/Unit

	Equip	Support	Install-Const	Other	Total
Az	80.0	24.5	32.3	25.4	
El-1	51.5	24.5	32.3	25.4	
DME	54.0	7.3	9.5	5.0	
Synch	6.3	3.6	4.7	2.5	
Remote Equip	21.6	7.8	9.5	7.9	
Total	213.4	67.7	88.3	66.2	222.2
Shipboard (single)	500.0	--	--	--	200.0

TABLE FOUR (B)

MILITARY MLS GROUND SYSTEM UNIT COST - NON RECURRING
(Thousands)

Austere (single) Cost/Unit

	Equip	Support	Install-Const	Other	Total
Az	30.6	20.3	29.0	14.0	
El-1	28.6	20.3	29.0	14.0	
DME	30.0	5.8	8.3	4.0	
Synch	5.0	2.9	4.1	2.0	
Remote Equip	4.6	2.9	4.2	2.0	
Total	98.8	52.2	74.6	36.0	162.8
Tactical (Colocated)	120.0	18.0			18.0
Tactical (split site)	250.0	37.0			37.0
Tactical (flexible) Army	150.0	22.0			22.0

TABLE FOUR (C)

MILITARY MLS AVIATION SYSTEM UNIT COST - NON RECURRING
(Thousands)

Advanced Cost/Unit

	Equip (dual) T*	Equip (single) H**
Az, El-1, El-2, Bach Az, Aux data	14.0	7.0
Antennas - front, back	.3	.3
Antenna switching	1.5	1.5
Control Box	1.0	.5
Aux Data Display	2.0	1.0
Map Display	8.5	--
DME - L band Flare (TACAN Mod)	4.0	2.0
Conversion to Ku band - El-2, Ant	--	1.6
Total	31.3	13.9
Support (spares, test equip, training)	4.8	2.5
Total	36.1	16.4

* Bombers, transport, tankers, patrol

** High performance jet

TABLE FOUR (D)

MILITARY MLS AVIATION SYSTEM UNIT COST - NON RECURRING
(Thousands)

Standard Cost/Unit

	Equip (dual) T*	Equip (single) H**
Az, El-1, El-2, Bach Az, Aux Data	14.0	7.0
Antenna front	.2	.2
Control Box	1.0	.5
Aux Data Display	2.0	1.0
Map Display	8.5	--
DME - L band (TACAN Mod.)	4.0	2.0
Conversion to Ku band - El-2, Ant.	--	1.6
Total	29.7	12.3
Support (spares, test equip, training)	4.6	2.3
Total	34.3	14.6

* Bombers, transports, tankers, patrol

** High performance jet

TABLE FOUR (E)

MILITARY MLS AVIATION SYSTEM UNIT COST - NON RECURRING
(Thousands)

Austere Cost/Unit

	U.S. Army Equip (single)	USAF/U.S.Navy Equip (single)
Angle Rec/r Processor	3.5	3.5
Conversion to Kuband-El-2, Ant	1.6	1.6
L Band DME	2.5	--
Antennas (2)	.2	.2
Control box/Display	1.2	1.2
Total	9.0	6.5
Support (spares, test equip, training)	1.9	1.5
Total	10.9	8.0

TABLE FOUR (F)

SUMMARY

MILITARY MLS GROUND SYSTEM UNIT COSTS - NON RECURRING
(Thousands)

GROUND

	Equip/Unit	Support-Installation-Const-Other
Advanced (Dual)	516.8	506.8
Standard (Dual)	213.4	222.2
Standard (Shipboard) single	500.0	200.0
Austere (Single)	98.8	162.8
Tactical (Colocated)	120.0	18.0 (Support only)
Tactical (Split-site)	250.0	37.0 (Support only)
Tactical (Flexible) Army	150.0	22.0 (Support only)

TABLE FOUR (G)

SUMMARY

MILITARY MLS AVIATION SYSTEM UNIT COST - NON RECURRING

(thousands)

	Equip/Unit	Support (spares, test equip, documentation)	Total
Advanced			
Dual (T)*	31.3	4.8	36.1
Single (H)**	13.9	2.5	16.4
Standard			
Dual (T)*	29.7	4.6	34.3
Single (H)**	12.3	2.3	14.6
Austere			
Single U.S. Army	9.0	1.9	10.9
Single USAF/U.S. Navy	6.5	1.5	8.0

* Bombers, transport, tankers, patrol

** High performance jet

TABLE FOUR (H)

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